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US Army Corps
of Engineers
Water Resources
Support Center

Management of Bottom Sediments Containing Toxic Substances

Proceedings of the 8th U. S./Japan
Experts Meeting

8-10 November 1982
Tokyo, Japan

Thomas R. Patin, Editor

July 1984

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The 8th U. S./Japan Meeting on Management of Bottom Sediments Containing [illegible] Substances was held 8-10 November 1982 in Tokyo, Japan. The meeting is [illegible] through an agreement with the U. S. Army Corps of Engineers and [illegible] Ministry of Transport to provide a forum for presentation of papers [illegible] discussions on dredging and disposal of contaminated sediment.

PREFACE

The 8th U. S./Japan Meeting on Management of Bottom Sediments Containing Toxic Substances was held 8-10 November 1982 in Tokyo, Japan. The meeting is held annually through an agreement with the U. S. Army Corps of Engineers and the Japan Ministry of Transport to provide a forum for presentation of papers and in-depth discussions on dredging and disposal of contaminated sediment.

COL Maximilian Imhoff, Commander and Director of the Water Resources Support Center (WRSC) at the time of the meeting, was the U. S. Chairman. Mr. Yasuo Okada, Ministry of Transport, Tokyo, Japan, was the Japanese Chairman.

Coordinator of the organizational activities and editor of this report was Mr. Thomas R. Patin, program assistant, Dredging Operations Technical Support Program (DOTS), U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. Mr. Charles C. Calhoun, Jr., was Program Manager, DOTS. At the time of publication of this report, COL George R. Kleb was Commander of WRSC.

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William R. Murden	CE, Chief, Dredging Division, WRSC
Neill E. Parker	CE, Coastal Engineering Research Center
Jim M. Mansky	CE, New York District
Richard K. Peddicord	CE, Waterways Experiment Station
Willis Pequegnat	Tereco Corporation
Herbert R. Haar	Board of Commissioners, Port of New Orleans
I. Wilder	U. S. Environmental Protection Agency
J. O'Connor	New York State University Medical Center
Vito Andreliunas	CE, New England Division
Ron Vann	CE, Norfolk District
Raymond L. Montgomery	CE, Waterways Experiment Station

Japanese Delegation

Yasuo Okada, Cochairman	Bureau of Ports and Harbours, Ministry of Transport (MOT)
S. Kasajima	Port and Harbour Bureau, City of Osaka
Y. Shiratori	Port and Harbour Research Institute, MOT
F. Kodama	Kasumigaura Work Office, Ministry of Construction (MOC)
Tatsuo Yoshida	Bottom Sediment Management Association
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Y. Baba	Public Works Research Institute, MOC
Tadashi Otsuki	Dredging and Reclamation Engineering Association
M. Hosomi	Environmental Agency
K. Nikaido	Nagoya Prefecture Government
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E. Sato	Japan Dredging and Reclamation Engineering Association
Hiromi Koba	Japan Dredging and Reclamation Engineering Association
A. Kaneko	Japan Dredging and Reclamation Engineering Association

AGENDA

8th U.S./JAPAN EXPERTS MEETING ON MANAGEMENT
OF BOTTOM SEDIMENTS CONTAINING
TOXIC SUBSTANCES

Tokyo, Japan

8-10 November 1982

Cochairmen

Mr. Yasuo Okada

Director, Environmental Protection Division
Bureau of Ports and Harbours, Ministry of Transport

COL Maximilian Imhoff

U. S. Army Corps of Engineers, Water Resources Support Center

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The 8th U.S./Japan Experts Meeting on Management of Bottom Sediments Containing Toxic Substances was held by the United States (Colonel Maximilian Imhoff, Commander/Director, Water Resources Support Center, U.S. Army Corps of Engineers) and the Japanese (Yasuo Okada, Director, Environmental Protection Division, Ports and Harbours Bureau, Ministry of Transport) Co-chairmen Nov. 8-10, 1982, at Tokyo, Japan. The purpose of the conference was to exchange information in both regulatory and technical areas relevant to bottom sediment management and to explore areas where joint efforts would be fruitful.

The United States and Japanese experts presented papers on several technical and managerial subjects, including: public works aiming at improvement of port and marine environment in Japan; dredging works in Osaka Port, Lake Kasumigaura, Lake Suwa, and the James River; experiments and studies for physical and chemical characteristics of bottom sediment; studies on toxic materials accumulated in organisms; legal restrictions, present condition, and new methods for dredged material disposal; advances in dredging technology including new equipment and operational techniques (Drag head, Clean-up, Pneuma pump and Refresher); dredging technologies and methods for dredged material disposal with due regard to the environmental impact; and emergency response equipment to clean up hazardous chemical release.

The United States and Japanese attendees consisted primarily of engineers, biologists, and chemists from administrative agencies, universities, port authorities, and related associations of engineering companies. There was general agreement that this conference was highly successful in meeting its major goal: to exchange the most recent information on management techniques and the environmental effects of sediments containing toxics and other pollutants. Consistent with the provisions of the memorandum of understanding, the next meeting will be held in the United States and the dates will be decided jointly by the Co-chairmen.

Director, Environmental
Protection Division,
Ports and Harbours Bureau,
Ministry of Transport

Yasuo Okada
November 10, 1982

Commander/Director, Water Resources
Support Center, U.S. Army Corps
of Engineers

Col. Maximilian Imhoff
November [illegible]

PUBLIC WORKS AIMING AT IMPROVEMENT OF PORT AND MARINE ENVIRONMENT IN JAPAN

Yasuo Okada
Director, Environmental Protection Division
Bureau of Ports and Harbors, Ministry of Transport

INTRODUCTION

Port and marine environment improvement works in Japan are carried out as a part of port improvement works.

Port improvement works are systematically carried out by formulating a Five-Year Plan for Port Improvement under the Law for Emergency Measures of Port Improvement.

The current Five-Year Plan for Port Improvement is the sixth plan and covers the period from fiscal 1981 to 1985 with a total investment of ¥4,260 billion. This plan lists "promotion of works aimed at the realization of pleasant port and marine environment" as one of its important tasks. The plan is thus intended to step up the improvement of port and marine environment by allocating about 1/10 of the total investment to it.

These works include marine environment improvement works and studies for materialization of port works conducted by government directly, works to provide facilities for preventing oil pollution of seawater, and port pollution prevention works and port environment improvement works conducted by a port management body with government subsidies. Table 1 shows the trends of the expenditure for port and marine environment improvement works.

MARINE ENVIRONMENT IMPROVEMENT WORKS

These works are intended to prevent marine pollution and to conserve the marine environment. In particular, accumulation work for floating refuse and oil has been carried out in badly polluted waters outside port and fishing port areas since 1974 as government-executed works.

Cleaning work for floating refuse and oil is scheduled to be carried out in 1982 as in the previous year in three areas of Tokyo Bay, Ise Bay, and the Seto Inland Sea.

The fleet for marine environment improvement work now comprises 16 ships with a newly constructed combined-use ship both for refuse and oil. The system of cleaning refuse and oil floating in inland seas and bays has now been roughly completed (see Table 2).

Table 1. Trends of the Expenditure of Port and Marine Environment Improvement Works

(Unit: ¥ million)

	1976	1977	1978	1979	1980	1981	1982	
Marine Environment Improvement Works	847	802	1,034	1,423	1,503	1,746	1,870	Cleaning work for floating refuse and oil in badly polluted inland seas and bays (excluding port areas).
Studies for Materialization of Port Works	-	-	-	500	650	780	780	Surveys necessary for conducting bottom sediment clarification works and those necessary for projecting interprefecture waste disposal site.
Works to Provide Facilities for Preventing Oil Pollution of Sea Water	114	396	61	20	80	80	78	Construction or improvement of facilities for treating waste oil from ships.
Port Pollution Prevention Works	5,678	6,880	6,742	7,793	6,138	7,861	7,746	Bottom sediment dredging, clean water pouring, and other works for the prevention of port pollution.
Port Environment Improvement Works	29,812	38,411	36,682	48,123	44,400	39,825	39,886	Works for improving port environment comprising the following:
Coastal Waste Disposal Site	22,865	29,763	28,550	40,470	36,698	32,865	32,770	Construction or improvement of bulkheads for coastal waste disposal sites.
Marine Wastes Disposal Facilities	725	1,249	493	170	274	129	-	Construction or improvement of facilities for disposing wastes accumulated from ships and port areas.
Construction of Cleaning Vessels	200	55	94	100	184	113	78	Construction of vessels necessary for cleaning port areas.
Removal of Sunken Vessels and Hulk	80	234	-	-	-	-	-	Removal of sunken vessels and hulk in port waters.
Storing of Materials for the Prevention of Port Pollution	326	-	-	-	-	-	-	Storing of oil fence necessary for the prevention of oil pollution in port areas.
Park Facilities, etc	5,608	7,110	7,545	7,383	7,244	6,718	7,038	Construction or improvement of facilities such as parks and open spaces for the improvement of port environment.
Total	36,451	46,489	45,519	57,859	52,771	50,292	50,360	

Table 2. Deplcyment of Marine Environment Improvement Vessels

Type \ Waters	Tokyo Bay	Ise Bay	Seto Inland Sea	Total
Oil Cleaning Vessel	2	1	2	5
Floating Refuse Cleaning Vessel	2	-	4	6
Refuse/Oil Cleaning Vessel (dual-purpose)	-	1	4	5
Total	4	2	10	16

STUDIES FOR MATERIALIZATION OF PORT WORKS

These studies are conducted prior to the commencement of actual work to ascertain their economic and technical feasibilities. During the current fiscal year, a bottom sediment clarification plan is scheduled for Tokyo Bay, Ise Bay, and the Seto Inland Sea. An interprefecture waste disposal site in Tokyo Bay is also projected.

The former was explained at the 7th US/Japan meeting. The latter is designed to construct a waste disposal site at sea because it has become increasingly difficult to provide inland waste disposal sites in metropolitan zones.

In Osaka Bay, the main body of the bay for interprefecture waste disposal (Osaka Bay Interprefecture Coastal Area Environment Improvement Center) was cleared this March for actual work.

MARINE OIL POLLUTION PREVENTION WORKS

These works are intended to prevent marine pollution caused by oil through the treatment of waste oil such as ballast water generated in ships at reception facilities on land. Since 1967, the government has been providing port management bodies with subsidies for the waste oil reception facilities.

Construction of the facilities at major ports was completed in 1972.

Table [illegible]. Waste Oil Reception Facilities

(As of October 1, 198[illegible])

Operator	Number of Ports	Number of Operators
Port management bodies	3[illegible]	[illegible]5
[illegible] port management bodies	1[illegible]	1[illegible]
Waste oil treatment companies	[illegible]	28
Oil refiner[illegible]	[illegible]1	6[illegible]
Total	11[illegible]	1[illegible]1

[illegible] WORKS

[illegible] to improve the [illegible] of harmful sediment result- [illegible]

[illegible] adopted in these works. Table [illegible]

Table 4. Port Pollution Prevention Works in 1982

(Unit: ¥million)

Port	Area	Scope of Work	Plan for Fiscal 1982 Quantity	Costs	Subsidies	Pollutants
Otaru	Iron. i	Sediment dredging	$\times 10^3\ m^3$ 6.2	66	33	Organic sediment
Tokyo	Koto	"	142.5	1,070	535	"
Yokohama			28.6	46	23	
	Katabira river	"	17.3	29		"
	Ebisu, Daikoku	"	11.3	17		"
Nagoya			$\times 10^3\ m^3$ 21.9	493	87	
	Harbor (2)	Earth covering	1.8	93		Hg
	Oe river	"	20.1	400		Hg, PCB
Tsu Matsusaka	Harbor	Sediment dredging	$\times 10^3\ m^3$ 94.7	560	280	Organic sediment
Kinuura	Hekinan	"	22.6	68	34	"
Sakai Senboku	7 Senboku wards	Dust fence	179 m	40	20	
Osaka	Harbor	Sediment dredging	$\times 10^3\ m^3$ 190.9	710	355	Organic sediment
Himeji			48.7	355	178	
	Yaka	Sediment dredging	23.4	195		Organic sediment
	Shikama	"	10.3	65		"
	Aboshi	"	15	95		"
Amagasaki-Nishinomiya-Ashiya			62.4	264	132	
	Nishinomiya	Sediment dredging	6.8	30		Organic sediment
	Amagasaki	"	55.6	234		"
Higashi Harima	Beppu	"	9.2	44	22	"
Minamata	Hyakken	"	267	4,030	882	Hg
	Total	Sediment dredging	$\times 10^3\ m^3$ 872.8	7,746	2,581	
		Earth covering	$\times 10^3\ m^3$ 21.9			
		Dust fence	179 m			

PORT ENVIRONMENT IMPROVEMENT WORKS

Coastal waste disposal site

These sites are designed to receive all wastes including dredged materials, marine wastes resulting from cargo handling, urban wastes, and industrial wastes.

It has become increasingly difficult to obtain sites in urban areas for final disposal of wastes because of the progress in urbanization. Therefore, the demand for water areas for final disposal has increased in recent years.

There are also strong demands for land to develop or renew port areas.

In response to such social needs, the government has been providing port management bodies with subsidies for the construction of bulkheads of waste disposal sites since 1973.

The list of wastes dumped in the disposal site is headed by surplus soil produced by inland construction works, followed by dredged material, general wastes, and industrial wastes. Of the annual total of about 280 million tons of general wastes and industrial wastes produced in 1979, about 140 million tons went to final disposal, of which 6.9 million tons or 4.9% were disposed of in coastal disposal sites.

Construction of cleaning vessels

Ports are generally closed waters, preventing frequent exchange of seawater. As a result, the refuse which flows in from rivers and that produced by port activities drifts in stagnant areas in ports, thus interfering with navigation and marine activities. Moreover, the drifts often cause environmental pollution through putrefaction, foul smells, and deposition, resulting in water pollution and sludge. Accordingly, prompt accumulation of this refuse while still floating is desirable.

The government has been providing port management bodies with subsidies for the construction of cleaning vessels necessary for the accumulation of oil and floating refuse since 1974. Sixteen cleaning vessels have thus been constructed in 15 ports as of 1981.

Parks and open spaces

We are also creating a pleasant port environment by providing greens, open spaces, rest houses, etc., so that the ports can serve the local residents.

Accordingly, the government provides subsidies for those port management bodies which undertake the improvement of port environment by providing

greens, open spaces, etc., within their port areas. Those so far completed draw families on holidays and serve as a place of relaxation where the citizens can get familiar with a port.

In 1980, greens were provided at 81 ports throughout the country at a total cost of ¥7.2 billion, accounting for 3.7% of the total urban park improvement cost of ¥194 billion.

REMOVAL OF BOTTOM SEDIMENTS IN OSAKA PORT BY THE PNEUMA PUMP DREDGE "SHUNKAI"

Shiro Kasajima

Manager of the Construction Division
Port and Harbour Bureau, City of Osaka

ABSTRACT

The Osaka Port, which is one of the representative ports in West Japan situated at the innermost part of Osaka Bay, has been suffering from the sediment of mud polluted with organic substances on the bottom of rivers such as Aji River, Shirinashi River, and Kizu River due to wastewater from factories and city sewage, which have caused deterioration of the environment through pollution of water and generation of a foul smell.

As a countermeasure, the Authority of Osaka City, having noticed the excellent performance of the Pneuma pump system, undertook the first mud dredging experiment in Japan with that system (which was introduced from an Italian firm S.I.R.S.I. in December 1971). Through this experimental dredging, the suitability of the Pneuma pump system to the dredging of polluted mud was well proved.

As a part of the pollution control project of the port and harbor, the Bureau completed the Pneuma pump dredge "ShunKai" in July 1974, then organized a dredging squadron with hopper barges that had undergone the necessary modifications. The squadron has engaged in dredging operations of polluted mud since November 1974 until the present day.

This paper introduces the Pneuma pump dredge "ShunKai" and the results of the squadron operation.

INTRODUCTION

The Port and Harbor Bureau has developed a new dredging process, the Pneuma pump system, which is capable of dredging a high solids concentration at any depth according to the configuration of the sea bottom without fear of secondary pollution. The Bureau has also built a new dredge to promote Japan's pollution control project. This system was built because:

(1) unless care is taken when mud on the water bottom is dredged by a conventional grab dredge, the grab might penetrate the layer of muddy sediment and dig into the comparatively hard soil of the sea bottom, and, when lifting the grab, the adhering mud would cause contamination of adjacent waters; and (2) if dredging is performed by conventional suction dredges and the mud transported to the dumping grounds on board box-shaped hopper barges, it would not be economical due to a very low solid concentration.

OPERATIONAL PRINCIPLE OF THE PNEUMA PUMP

The Pneuma pump system consists of a pump body, a distributor, and a compressor. The pump body is composed of three cylindrical tanks that are used as one assembly. Each tank is fitted with an inlet port, an outlet port, and various valves. The distributor automatically controls charging of compressed air to each tank with a constant cycle and then discharging it to the atmosphere. The compressor supplies the compressed air, the capacity of which may vary according to the required performances, but its pressure is normally 7.5 atm.

When the pump body is lowered to the sea bottom with the distributor in operation, the seawater comes into the tank lifting the inlet valve. Then, compressed air is delivered via the distributor, and the seawater in the tank is displaced (by the action of air similar to that of piston) through the mud discharge pipe. Then, the compressed air that filled the tank is discharged through the distributor into the atmosphere and the air pressure within the tank returns to atmospheric level. At this moment, the mud at the seabed is forced into the tank due to the head difference between the surface and the bottom and horizontal movement of the suction port. Thereafter, by repeating the above-mentioned operations, the mud is discharged through the mud pipes. As this operation is repeated within a tank and the three tanks work continuously with a constant interval, the mud is discharged continuously from the mud pipe as shown Figure 1.

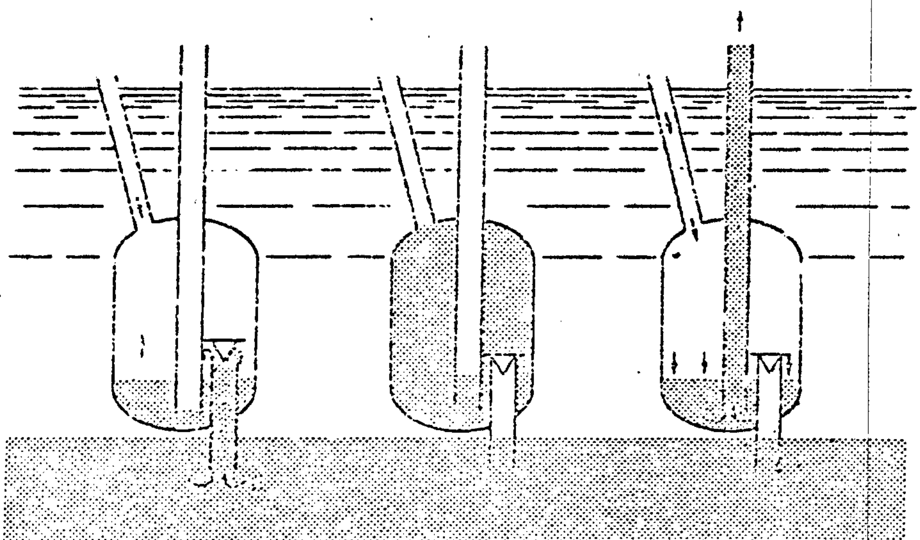


Figure 1. Principle of Pneuma pump

DREDGING TEST OF MUD WITH THE PNEUMA PUMP SYSTEM

One Pneuma pump 300/60 system and distributor were installed onboard the crane barge "No. 1 Kongo" and one on the grab dredge "ShunKai." The dredging tests were performed along the lower part of Kizu River, the innermost part of Aji River Inner Port, Zone No. 1 Inside Port, and in front of wharfs A and I of South Port with the following results being obtained:

(1) When dredging at a constant speed of from 1-3 m/min, the mud can be dredged with a very high net solid concentration by volume as shown in Tables 1 and 2. The quantity of discharge also can exceed the rated capacity of the Pneuma pump 300/60.

(2) The mud piled up on the guarding rubble mound in front of the wharf can be removed without impairing the surface of the rubble mound.

(3) The trawling speed should be kept at the low level of 1-3 m/min and constant.

(4) Among the various types of shovels tested, the three shovel type, the big shovel type, and the leg shovel type, the three shovel type was effective for both mud and soft clay. The shape of the shovels should be designed to cope with the conditions of the site of dredging.

(5) Deposit of rubbish on the seabed or river bed caused little harm to dredging.

(6) If the three shovel type is used, the blue-gray clay, the most common soil in Osaka Port, can also be dredged.

(7) Iron scraps and stones of small quantity can be dredged as they are.

(8) The degree of transparency of water near the surface at the dredging site declines by about 15-20 cm.

(9) For mud having a very high solid concentration such as that dredged by the Pneuma pump system, the application of pan-floc is not suitable.

CONSTRUCTION SPECIFICATIONS OF PNEUMA PUMP DREDGE "SHUNKAI"

(1) Basic Design Requirements

1. Soil to be dredged
Deposit of mud or soft clay in the duplication area of a river and port and at the river mouths.

2. Quantity of soil to be dredged
Dredging, transportation, and discharge of about 1,000 m^3 per day or 210,000 m^3 per year.

3. Weather, sea, and geographical conditions
The sites of operation are within the calm water area in the Osaka

Table 1. Summary List for Percentage of Water Content

Location of test	Attachment	Depth of shovel below sea bottom	Percentage of water content of the samples taken: Max. percentage of water content	Min. percentage of water content	Average percentage of water content	Mean value of samples having comparatively low water content	Percentage of water content of boring samples
Kizu River	Three shovel	2.5 m	401.6	245.7	315.0	281.6	222.3
	Big shovel	1.5	794.7	311.2	500.3	318.6	233.5
		2.0	814.1	320.5	533.7	351.4	233.5
	Three legs	1.7	-	-	709.1	-	222.3
Aji River	Three shovels	2.6	764.6	388.7	515.3	432.2	170.8
South Port A Wharf		1.3	269.4	166.8	211.1	181.9	116.7
		1.8	223.5	160.7	184.2	168.9	116.7
Inner Port, Zone No. 1	Three shovels	0.7	-	-	240.9	-	194.5
		1.5	570.2	156.2	233.9	189.9	170.9 (147.3)
		Below clay 0.5	303.6	138.3	214.6	176.5	120.3
South Port I Wharf		0.15 ~ 0.2	2950.6	2663.3	2855.0	-	-

Remarks: The samples are directly taken from the exit of the mud loading pipe.

Table 2. Comparison of Net Solid Concentration in Volume Between Boring Samples and Those from Dredged Soil

Location of test	Attachment	Depth of shovel below sea bottom	Net solid concentration in volume: Ratio to minimum solid concentration	Ratio to maximum solid concentration	Ratio to average solid concentration	Ratio to samples having comparatively high solid concentration
Kizu River	Three shovels	2.5 m	0.60	0.92	0.74	0.82
	Big shovel	1.5	0.33	0.78	0.51	0.77
		2.0	0.32	0.76	0.48	0.70
	Three legs	1.7	-	-	0.35	-
Aji River	Three shovels	2.6	0,26	0.49	0.38	0.45
South Port A Wharf	Three shovels	1.3	0.50	0.75	0.62	0.70
		1.8	0.59	0.78	0.69	0.75
Inner Port Zone No. 1	Three shovels	0.7	-	-	0.83	-
		1.5	0.34	0.95	0.77	0.92
		Layer of clay 0.5	0.46	0.90	0.63	0.74

Port where there is little influence of wind and waves. The rivers are tidal and the velocity of flow is low, 0.5-1.0 kt along the mainstream of Aji River and 0.5 kt along Shirinashi and Kizu Rivers. For the weather and sea condition at the time of operation, the design should comply with the terms of "Standard of Design for Working Boats."

a) For the design of the hull, the maximum instantaneous wind velocity shall be 16 m/sec during operation.

b) The velocity of tidal current of 3 kts shall be considered during operation.

c) The wave height during operation shall be 0.5 m (1/3 significant waves).

d) The dredging depth shall be 15 m below the surface.

e) Process of disposal of dredged material shall be trawl dredging carried out by the dredge fitted with the Pneuma pump 450/80. The dredged mud is placed onboard 500-m^3 non-self-propelled hopper barges. The barges are pushed to the disposal site in the North Port, making three trips or more per day, where the mud is discharged.

(2) Design Considerations

1. Electro-hydraulic winches of stepless variable speed enable the vessel to travel at 1-5 m/min during dredging and 20 m/min maximum speed on the return trip after dumping.

2. The centralized control station for operation is provided as a labor-saving device.

3. To prevent noise generated by the air compressors, each compressor is confined in a separate soundproof enclosure with shock-absorbing rubber inserted between the machines and the hull.

4. Providing for the dredging along the narrow channels in the upper reach of rivers, fairleaders of christmas tree type are fitted at the bow and the stern part of the vessel.

5. The ladder system is used for lowering and lifting the Pneuma pump.

6. To maintain an agreeable working environment (including living area, operating room, etc.), special silencers are used for exhaust noise.

7. A loader system with mud discharge pipes leading to the hopper barges moored along both sides of the dredge is used for loading the mud.

The specifications of the "ShunKai" and diagrams are shown in Table 3 and Figure 2, respectively.

Table 3. Specifications of "ShunKai"

o Hull Part	
* Kind of Vessel	Non-self-propelled Pneuma pump dredge
Form of Vessel	Box type
* Principal Dimensions	
Length	25.80 m
Breadth	10.00 m
Depth	2.50 m
Draft (Designed full loaded)	about 1.46 m
o Engine Part	
* Prime Mover for Main Generator	1 set
Type	Vertical 4 cycle diesel engine
Maximum continuous output	125 PS
Number of revolution	1,200 rpm
* Main Generator	
Type	Closed drip-proof self-ventilating horizontal type
Output	100 KVA Fully loaded continuous rating
Voltage·No of Phase	225 V · 3 phase
Frequency·Number of Revolution	60 Hz · 1,200 rpm
o Deck Machinery	
* Maneuvering Winches	2 sets
Type	Electro-hydraulic
Capacity	7.5t x 5 m/min
Range of winding speed	1 - 20 m/min
* Ladder Winch	
Speed of Tapping and Lowering	About 3 m/min
Capacity	6t x 12 m/min
* Mud Loading Pipes	
Elevation Winches	2 sets
Speed of Elevation of Pipes	About 3 m/min
Capacity	0.5t x 6 m/min
o Dredging Part	
* Pneuma pump	1 system
Capacity	450 m^3/hr (for fresh water)
Maximum Air consumption	80 m^3/min
Maximum air pressure	7 kg/cm^2
Maximum dredging depth	15 m
* Air Compressors for Dredging	2 sets
Type	Rotary screw type single stage oil cooling
Capacity	25.5 m^3/min (of free air)
* Prime Movers for Air Compressors	2 sets
Type	Vertical 2 cycle diesel engine
Maximum continuous output	235 PS
Number of revolution	2,100 rpm

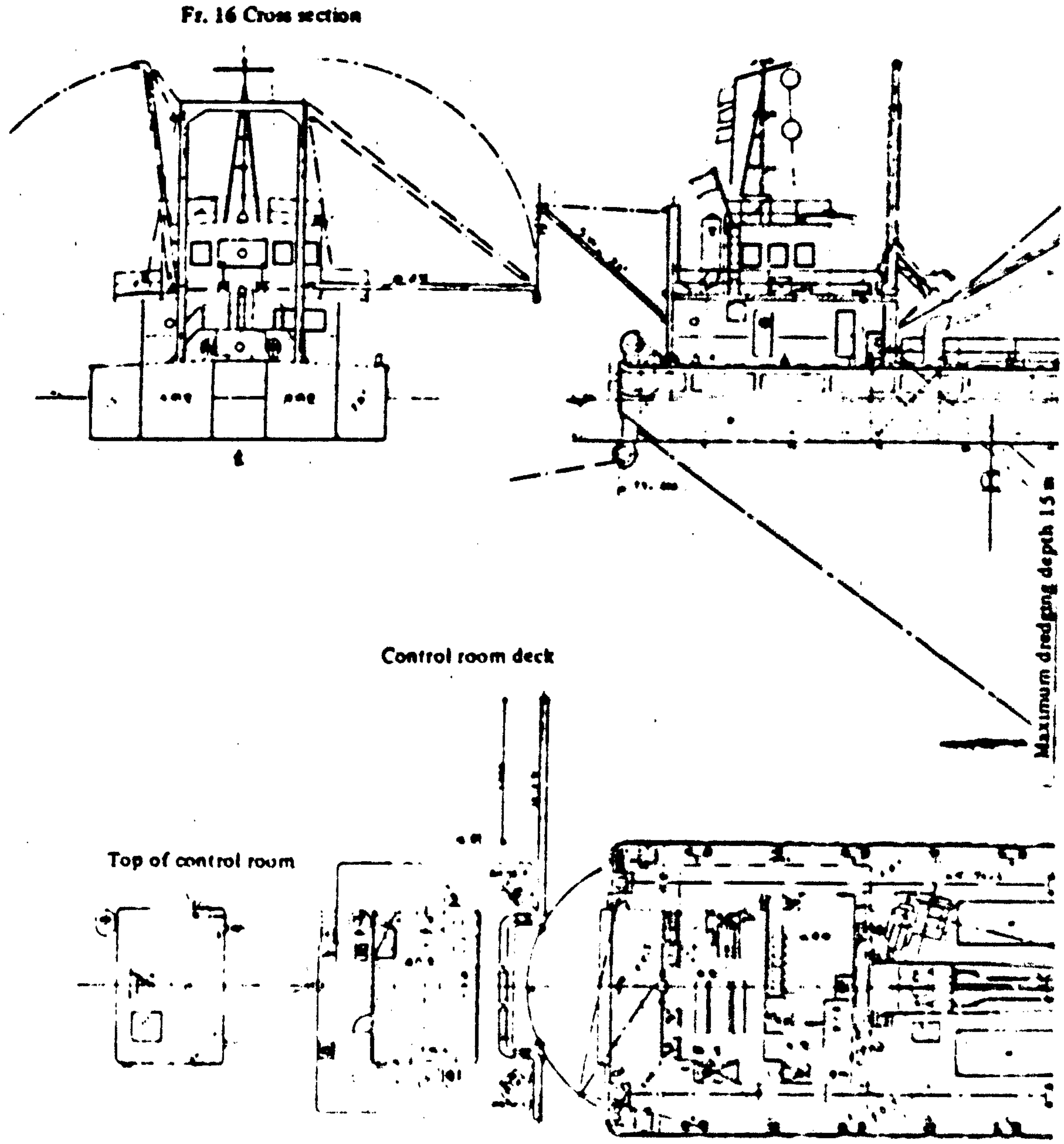
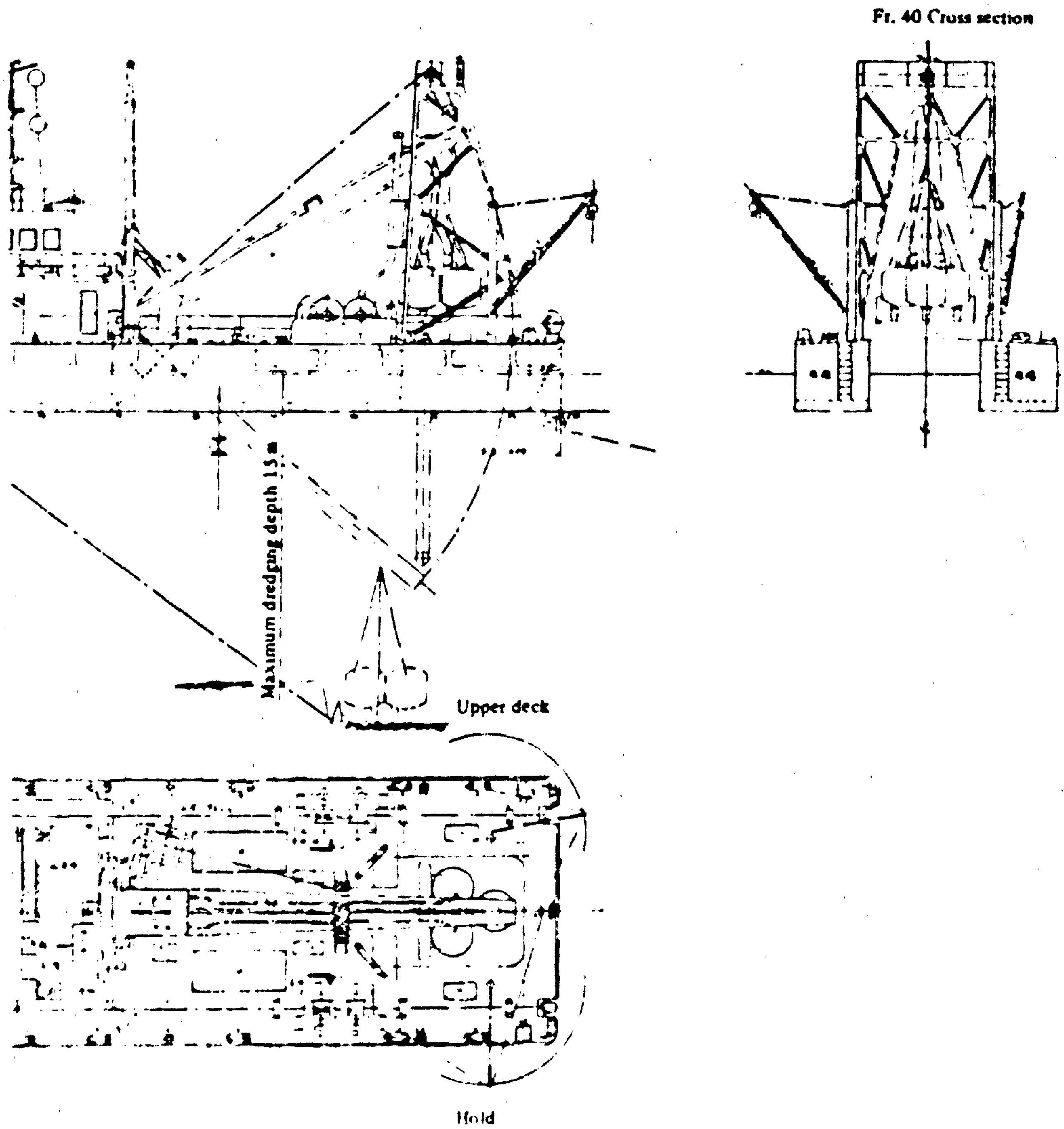


Figure 2. General arrange



re 2. General arrangement of "ShunKai"

2

ORGANIZATION OF SQUADRON

"ShunKai" is required to dredge the narrow upper reaches of the rivers in the city. The hopper barges of the existing pusher barge line system cannot be turned at the narrow part of the waterway; therefore, two non-self-propelled hopper barges of 350 m^3 capacity were remodeled into the box-shaped mud barges with 500 m^3 capacity able to be pushed either from bow or stern.

The squadron is organized with "ShunKai," a pusher tug, the two non-self-propelled mud barges, and a chartered non-self-propelled box-shaped mud barge of 500 m^3 capacity.

In August 1977, a non-self-propelled mud unloading barge of sand pump type (displacement 288.45 tons) was created by modifying the existing grab dredger "SeiKai" and installing the sand pump (mud discharging capacity 540 m^3/hr) of DP 100 BL Type manufactured by Toyo Electric Co., Ltd. Thus, the organization of the squadron of the total system from dredging, transporting, and unloading to final discharging is complete.

IMPROVEMENT OF DREDGING EFFICIENCY AND WORKING ENVIRONMENT

In 1976, when the dredging at the planned depth D.L.* -6.0 m was carried out, the operational efficiency was too low and the solid concentration of the dredged soil was much less than anticipated. Thus, improvement of the operational efficiency of dredging at shallow depths has been required.

As a possible countermeasure, installation of a vacuum pump at the exit of the distributor was examined, but the idea was abandoned because there was little margin both in the capacity of the generator and the space for installation. However, taking advantage of the surplus of compressed air when the dredging depth is shallow, the dredging efficiency can be raised by installing the breathrider (vacuum generator).

Installation of the breathrider vacuum gained 0.20 m of water column and allowed dredging at a depth about 1 m less than possible before. It further contributed to the improvement of dredging efficiency by remarkably reducing the chances of choking of the shovels with mud. This can be attributed to the fact that due to the effect of vacuum, the resistance against lifting the suction valves by the pressure of mud and the same in the air pipes between the pump bodies and the distributor during the cycle of delivery and suction of the compressed air is substantially reduced.

As a countermeasure for the offensive odor of hydrogen sulfide, an absorption tower (which simultaneously works as a silencer and a solid remover) was also installed. Within the tower the bad-smelling exhaust air is washed by a seawater shower, dehydrated and well diluted, and then released to the atmosphere after being led to the level of the topping mast. Thus, the offensive odor is successfully reduced. The flow diagram of the system is illustrated on the next page.

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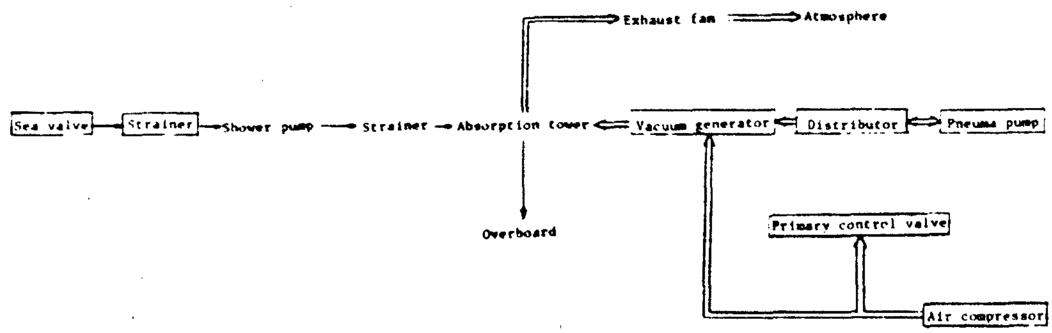
* D.L. = mean low water.



RESULT OF OPERATION BY "SHUNKAI" SQUADRON

Procedure of Operation

(1) Prior to operation, the geological survey of the dredging area is conducted and the thickness of mud to be dredged, ratio of water content, loss on ignition, specific gravity, etc., are determined.

(2) The trawling dredge is used and the dredged mud is loaded onto the mud barges of closed type. The volume of the muddy water is surveyed and sampled.

(3) The mud barges are pushed to the disposal site by the tug. The mud is discharged into the enclosed disposal site area surrounded by banks.

(4) The quantity of the dredged soil is estimated from the ratio of water content and the apparent specific gravity of the sample and the volume of muddy water.

(5) For guidance, the dredged sea bottom is surveyed by the echo sounder and confirmed.

Manner of Operation

By August 1977, the operations were carried out in the following manner:

Dredging .... by the Pneuma pump vessel "ShunKai"

Transportation ...... by a pusher tug and three mud barges of box type (one of which was chartered)

These operations were conducted by the Bureau. The prevention of secondary pollution is assigned to contractors. The disposal of surplus water is assigned to Osaka Industrial Wastes Management Public Cooperation.

Upon completion of the mud unloading vessel "SeiKai" (September 1977), the contracted operation of the barge unloader has been converted to direct operation by the Bureau. Other operations remain the same.

Results of Operation

Upon completion of "ShunKai," a series of tests was carried out to cope with the various operational conditions.

Whether or not the centralized control system would work satisfactorily was confirmed first and then the rate of mud discharge of each shovel, the air pressure and air volume in the pump bodies, the quantity of air consumed, etc., were investigated.

Noise was also measured at every noise and vibration preventive structure and was compared with the design value. Whether or not the anchors would have sufficient holding power to endure the load of trawling operation and whether the winches installed for the trawling operation would operate at the required speed for forward and astern travel were also investigated.

This operation began in November 1974 and by the end of March 1982 dredging of polluted mud and disposal had been carried out at the locations along Aji River, Shirinashi River, and Kizu River as shown in Figure 3. Table 4 gives the operation results, and Figure 4 shows the results of the echo sounding.

The annual summaries are also listed in Table 5 with respect to the dredged area and the quantity of dredged soil. The total dredged area and the quantity of dredged soil as of the end of March 1982 were 532,000 m^2 and 1,460,600 m^3, respectively, and the total quantity of soil removed was 2,551,700 m^3 with an overall average solid concentration of about 57%.

The annual record of operation of "ShunKai" is shown in Table 6. In the operational hours of "ShunKai," time required for shifting both ways between her moorings and the site of dredging and the same necessary for taking the bearings in order to fix the position of operation, about 400 hours per year total, and another 100 hours for cleaning, during which the rubbish from the muddy sediment is removed from the screen of the pump shovels, and time for waiting, meals, and cleaning of the vessel at her moorings are included.

Solid Concentration of Dredged Soil

The solid concentration of the dredged soil is supposed to be influenced by the grain size, thickness of the soil to be dredged, and the technique of operation, but the correlation among these is not clear. However, in the case of dredging by the Pneuma pump system, the deeper the water at the location of dredging, the stronger the thrust due to hydrostatic pressure. Consequently, a trend that the solid concentration increases proportionally to the water depth can be observed, although there is some dispersion in the relation between the water depth and the average solid concentration (see Figure 5).

Table 6 Result of Operation

Fiscal year	1974	1975	1976	1976	1976	1977	1977	1978	1978	1979	1980	1980	1981
Location of operation	Lower reach of Aji River Pier	Lower reach of Aji River Pier	Aji River Pier (North)	Shirinashi River lower reach 180 m from Suzubashi	Shirinashi River Suzubashi 120 m and 160 m	Shirinashi River Suzubashi	Kizu River Lower Reach from Tiдgate	Kizu River Downstream from Lower ... Ferry	Aji River, in front of Dolphin	Aji River in front of Silo	Aji River in front of North Port Canal	Kizu River Nakayama Steel Mill	Kizu River 9 months Shirinashi River 2 months
Period of operation	1974.11 - 1975.3	1975.4 - 1976.3	1976.4 - 1976.6	1976.7 - 1976.9	1976.10 - 1977.3	1977.4 - 1977.6	1977.7 - 1978.3	1978.4 - 1978.12	1979.1 - 1979.3	1979.4 - 1980.3	1980.4 - 1980.6	1980.7 - 1981.3	1981.4 - 1982.3
Dredged area	23,500 m^2	90,300 m^2	14,800 m^2	12,600 m^2	23,100 m^2	8,100 m^2	35,500 m^2	[illegible]	41,500 m^2	75,000 m^2	21,100 m^2	85,600 m^2	71,000 m^2
Planned depth	-10 m	-10 m	-6 m	-7.5 m	-7.5 m or -10 m	-7.5 m	-6.5 m	-7.0 m	-10 m	-10 m	-10 m	-9.1 m	(Shirinashi) -10 m (Kizu) -9.5 m
Average thickness of dredging	3 m	1.0 m	2.5 m	2.9 m	2.9 m	3.5 m	2.0 m	2.8 m	1.0 m	1.3 m	1.3 m	1.0 m	2.0 m
Quantity of mud removed	177,900 m^3	350,000 m^3	73,600 m^3	86,200 m^3	176,200 m^3	92,500 m^3	260,500 m^3	255,800 m^3	101,500 m^3	268,700 m^3	104,200 m^3	222,100 m^3	384,500 m^3
Equivalent net quantity of soil	109,800 m^3	222,900 m^3	20,900 m^3	45,400 m^3	96,500 m^3	46,100 m^3	123,700 m^3	110,900 m^3	69,700 m^3	190,000 m^3	71,800 m^3	138,300 m^3	216,400 m^3
Average solid concentration	62%	64%	28%	53%	55%	50%	47%	43%	69%	55%	69%	61%	56% (Kizu 55%, Shirinashi 60%)
Quantity of mud removed per day	1,815 m^3	1,681 m^3	1,443 m^3	1,390 m^3	2,049 m^3	1,568 m^3	1,692 m^3	1,369 m^3	1,637 m^3	1,227 m^3	1,628 m^3	1,500 m^3	1,569 m^3
Net quantity of soil per day	1,120 m^3	1,072 m^3	410 m^3	732 m^3	1,135 m^3	784 m^3	803 m^3	680 m^3	1,124 m^3	868 m^3	1,121 m^3	920 m^3	883 m^3
Average percentage of water content of base soil	70.6%	75.7%	69.5%	65.3%	81.6%	66.3%	70.1%	69.3%	69.9%	73.2%	71.7%	76.2%	Shirinashi 79.6% Kizu 72.6%
Minimum percentage of water content	65.7%	67.5%	63.1%	51.6%	62.8%	49.2%	60.4%	53.8%	53.7%	60.5%	67.4%	55.5%	Shirinashi 73.5% Kizu 56.9%

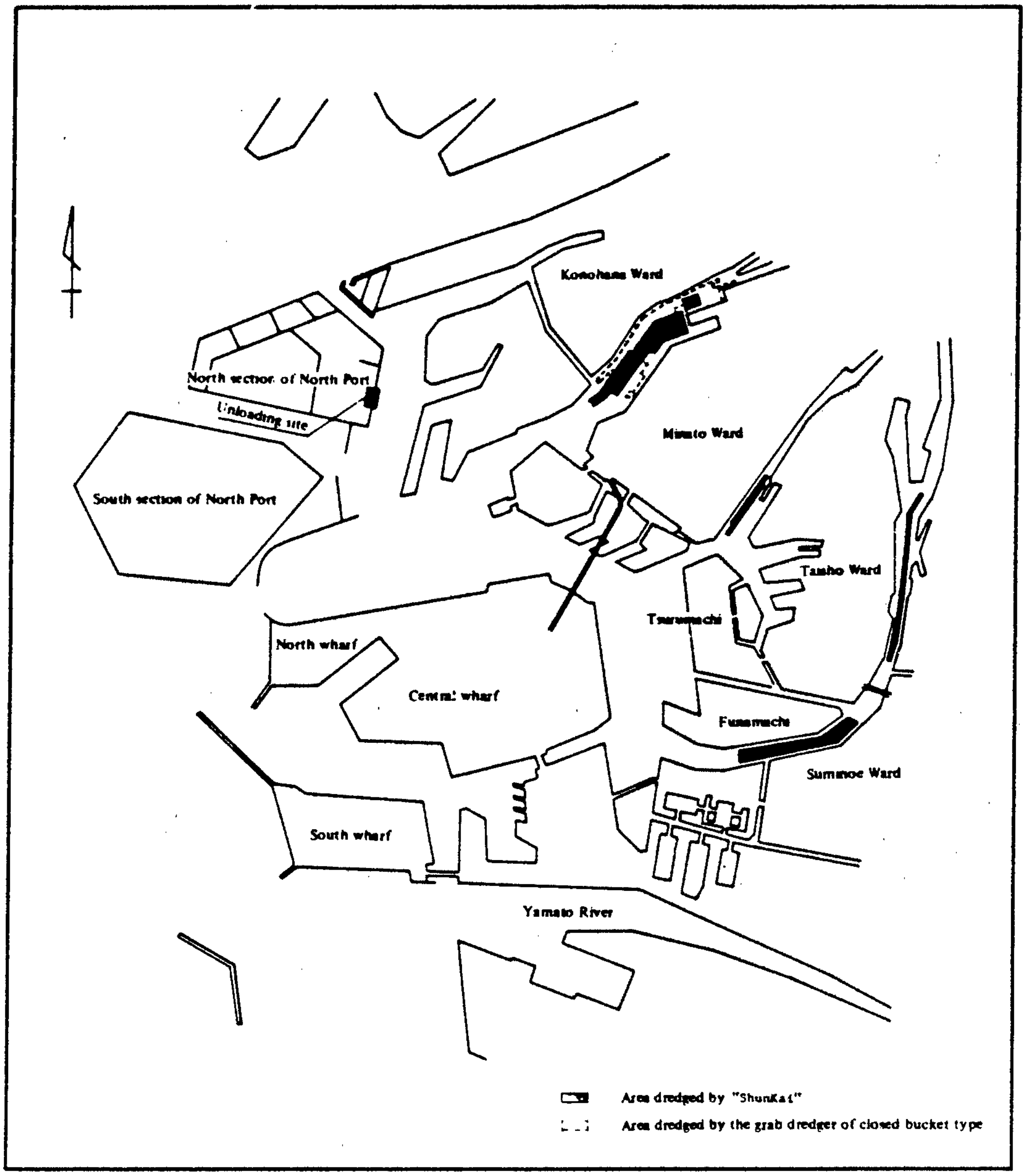


Figure 3. Dredging operation sites

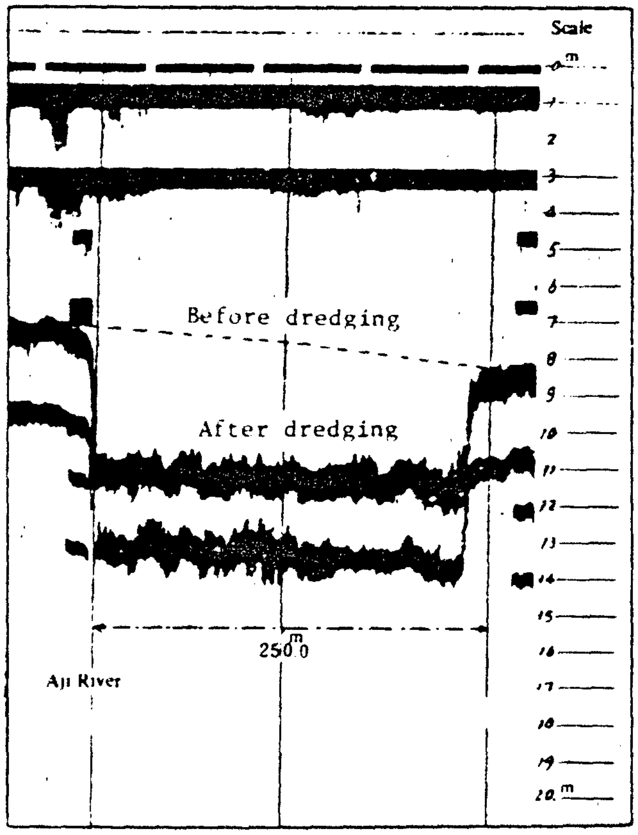


Figure 4. Record of echo sounding

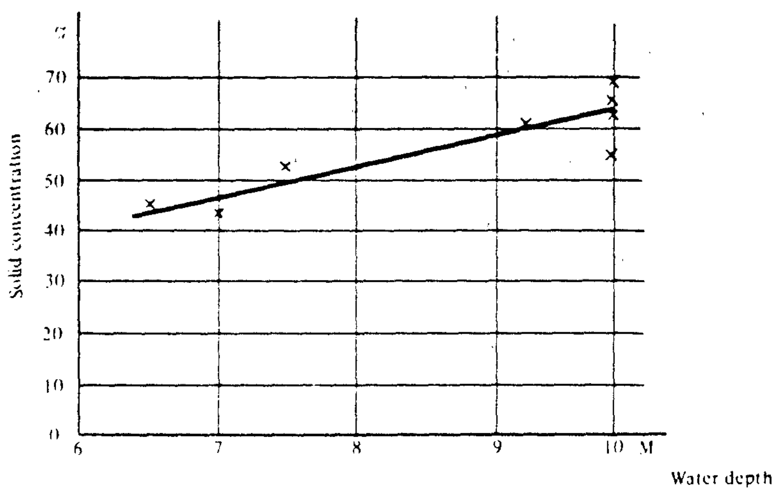


Figure 5. Water depth and solid concentration

Table 5. Dredged Area and Quantity of Soil Dredged for Every Fiscal Year

Fiscal year	Area dredged	Quantity of soil dredged
1974	23,500 m^2	109,800 m^3
1975	90,300	222,900
1976	50,500	162,800
1977	43,500	170,000
1978	71,500	180,600
1979	75,000	190,000
1980	106,700	208,100
1981	71,000	216,400
Total	532,000	1,460,600

Table 6. Summary of Operation of "ShunKai"

Fiscal year	No. of days on operation	No. of days out of operation	No. of days on service	Hours on service	Hours of operation
1974	98	15	113	1,018.20	782.40
1975	207	55	262	2,117.15	1,552.10
1976	200	69	269	1,965.00	1,408.15
1977	214	30	244	2,109.00	1,589.00
1978	222	33	255	2,093.30	1,501.40
1979	220	37	257	2,044.15	1,453.25
1980	212	42	254	1,958.30	1,387.45
1981	245	20	265	2,430.15	1,569.50

COMPARATIVE INVESTIGATION OF TURBIDITY AT WATER SURFACE ADJACENT TO DREDGING SITE

On March 9 and 27, 1979, turbidity of the water surface adjacent to the dredging site was investigated. According to the results, the Pneuma pump dredge makes the water at the lower layer turbid to a certain extent up to 50 m away, because the pumps are dipped in the bottom mud; however, practically no turbidity is observed in the upper and middle water layers.

The grab dredge with the clo. d bucket often operates with the bucket not completely closed after a g: .. due to the rubbish found scattered in the mud. Therefore, the turbidity 50 m away from the dredge occurs throughout all layers, surface to bottom, and tends to increase as the dredging continues.

As a typical example, the location of operation in Figure 6, the record of transparency and turbidity 5 hrs after the beginning of dredging in Table 7 and the comparison of the record of measured turbidity in Figure 7 are presented.

MEASURES FOR PREVENTION OF SECONDARY POLLUTION

The dredging operation by the Pneuma pump dredge causes the release of an offensive odor unique to the polluted mud, and an oily material mixed with light organic dust emerges forming films on the surface of muddy water discharged into the hopper barges. The smell and oily material must be properly disposed of and the dispersion of mud particles and suspended oily material must be prevented as well.

Measures Against Foul Smell

The polluted mud sediment at sea bottom is in a state of anaerobic fermentation and causes an offensive odor due to the gases generated such hydrogen sulfide, methacabutane, and thio-glycolic acid.

To handle the foul smell from the distributor, the release gas is thoroughly washed and diluted through the shower in the absorption tower and is then discharged into the atmosphere from a high position. For prevention of foul smell from the mud discharged, one bagful of deodorant agent (20 kg) is spread over one bargeful of mud. The deodorant is composed of 95% bentonite, 4% phyroligneous acid, and 1% papain enzyme and eliminates foul smells through the catalytic action and absorptive power of the ingredients.

Measures for Disposal of Oily Suspensions

When the polluted muddy sediment is pumped into the hopper barge, oily substances mix with minute organic substances and float on the surface, forming foamy scums. In order to dispose of these oily substances, a half can (18 litre) of neutralizer is first sprayed over a bargeful of mud. Then, after discharging the mud, the same quantity of neutralizer is sprayed along the boundary of the oil fences. These oil fences have curtains underneath that are stretched around the discharge nozzle of the mud pipe. (The curtain has a peripheral length of 300 m). The spraying is done by a pump and

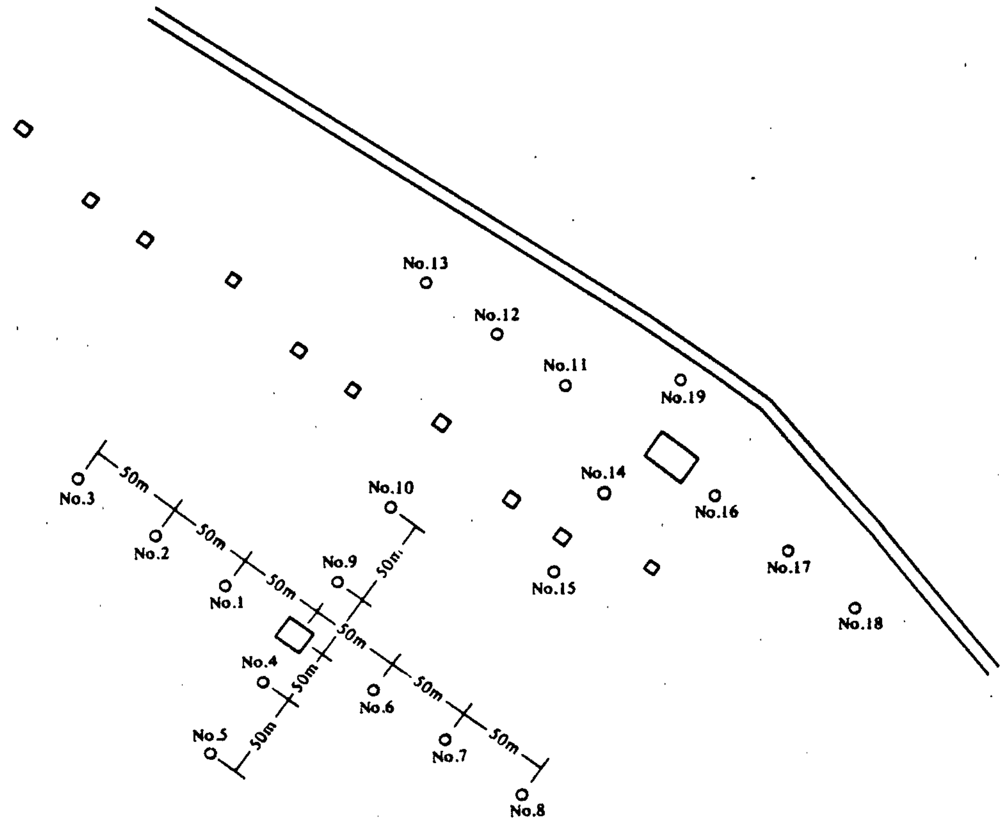


Figure 6. Turbidity survey in the vicinity of Aji River Dolphin

the neutralizer, diluted to about 20% solution, is ejected from the hose nozzle.

Prevention of Dispersion
of Discharged Soil and
Countermeasures for Surplus Water

Prevention of dispersion and outflow of the mud, and quality control of surplus water, both require a great amount of care. The disposal site, as is its nature, has to accept an enormous quantity of muddy water in addition to ordinary dredged soil, etc. Therefore, a facility for disposal of the surplus water is attached to the disposal site.

At the North Port disposal site, the result of the bottom soil test and the elution test is checked prior to disposal to ensure compliance with the standard two drainage canals, four precipitant mixing stations, and a monitoring facility for turbidity automatically measure, record, and watch the

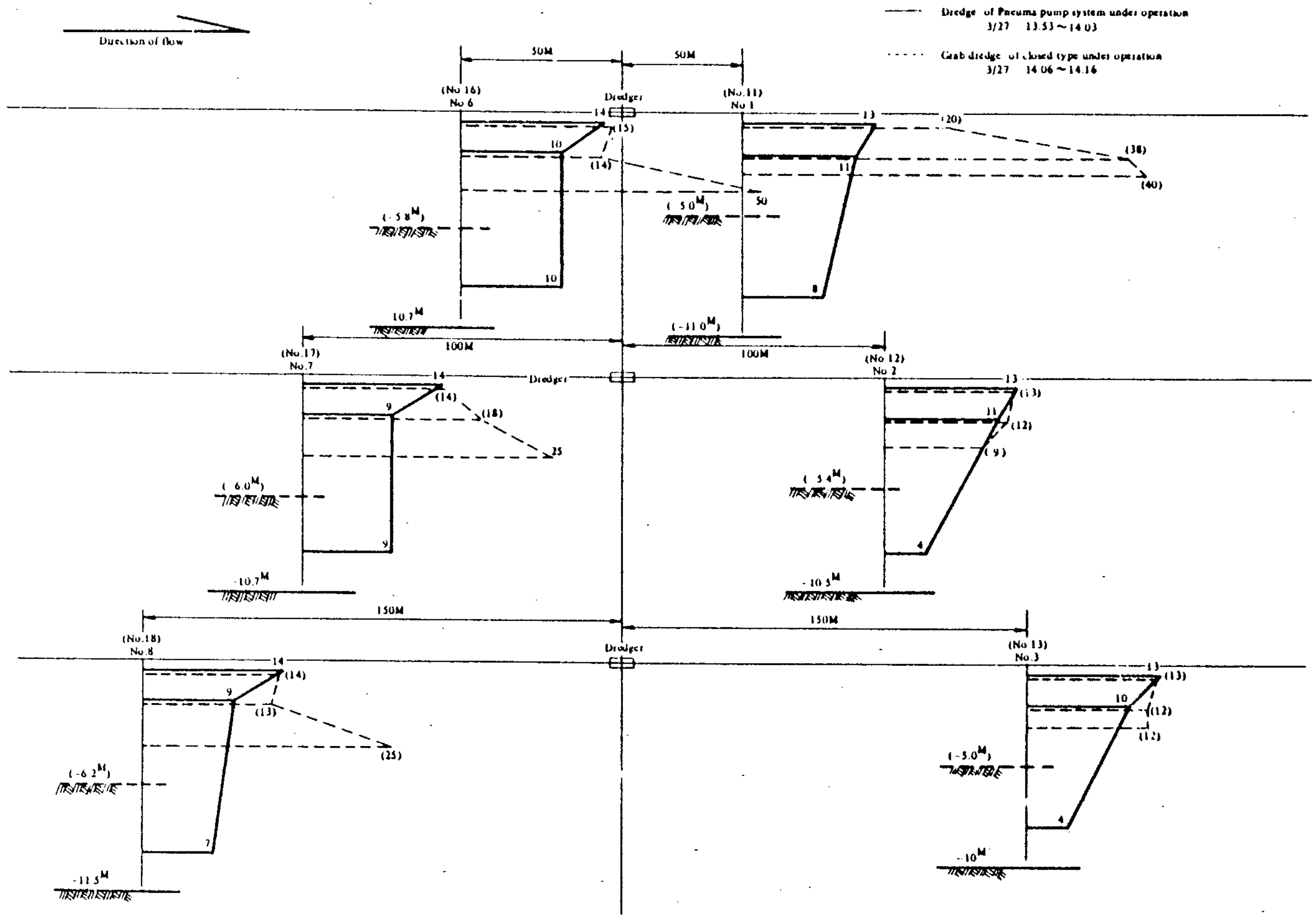


Figure 7. Comparison of turbidity

Table 7. Result of Survey on Transparency and Turbidity of Aji River

March 27, 1979

Weather: Fine, Temperature: 16°C During dredging operation at rising tide.

Point of measurement	Time of measurement	Depth of water	Transparency	Turbidity Upper layer	Turbidity Middle layer	Turbidity Lower layer	Remarks
Pneuma pump dredge							Sequence of measurement
No. 1	13:53	11.0	0.5	13.0	11.0	8.0	3
2		10.5	0.6	13.0	11.0	4.0	2
3	13:53	10.0	0.6	13.0	10.0	4.0	1
4		11.3	0.5	12.0	10.0	6.0	4
5		10.0	0.6	12.0	11.0	5.0	5
6		10.7	0.5	14.0	10.0	10.0	8
7		10.7	0.5	14.0	9.0	9.0	7
8		11.5	0.6	14.0	9.0	7.0	6
9		9.0	0.5	12.0	10.0	6.0	9
10	14:03	9.0	0.6	13.0	11.0	6.0	10
Grab dredge of closed bucket type							
No. 11		5.0	0.4	20.0	38.0	40.0	3
12		5.4	0.6	13.0	12.0	9.0	2
13	14:06	5.0	0.6	13.0	12.0	12.0	1
14		5.0	0.5	16.0	35.0	80.0	8
15	14:16	9.0	0.6	15.0	14.0	7.0	9
16		5.8	0.5	15.0	14.0	30.0	5
17		6.0	0.6	14.0	18.0	25.0	6
18		6.2	0.6	14.0	13.0	25.0	7
19		4.0	0.4	23.0	/	13.0	4

Upper layer: 0.5 m below surface   Middle layer: 2 m below surface
Lower layer: 2 m above water bottom

quantity of suspended substance and values of COD and pH so that the quality of surplus water can be controlled.

The device for discharging through slits at the end nozzle of the pipe line and the oil fence effectively prevent the primary dispersion of soil particles and promote their precipitation.

Transparency tests of the water samples taken from the surface, middle, and bottom layers outside the oil fence show that turbidity disappears 400-500 m outside the oil fence.

FUTURE PROGRAM OF DISPOSAL OF POLLUTED MUD SEDIMENT

At present, the operations for 1982 of the Five Year Plan of Prevention of Pollution Project of Osaka Port (1981 - 1985 fiscal year) are under way. The following quantity of disposal is planned for each river in and after 1982:

Aji River	278,900 m^3
Shirinashi River	141,300 m^3
Kizu River	157,900 m^3
Total	578,100 m^3

For guidance, the total dredged soil accepted by the site of disposal in North Port was 11,887,000 m^3 by fiscal year 1981. Although the polluted mud sediment of 1,461,000 m^3 dredged, transported, and discharged by the "ShunKai" squadron is included in the above, this quantity accounts for only 12% of the total dredged soil.

In 1984, acceptance of the dredged soil in the Northern Area will be terminated. In and after 1984, acceptance and disposal of general dredged soil and the polluted mud will be made at the Southern Area (capacity of acceptance 46,000,000 m^3).

The Bureau intends to convert both disposal sites, the Northern and Southern area of North Port, into newly reclaimed land through intensive application of various soft ground methods of improvement. Then these new lands can contribute to the future development of Osaka Port.

POSTSCRIPT

The author is confident that the very emergence of "ShunKai" has opened a new way to the dredging of polluted mud. He also earnestly hopes to attain more complete mud dredging techniques through further application of new technologies in the future.

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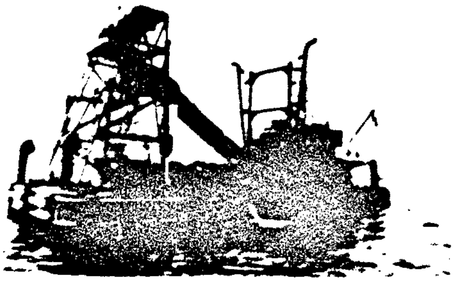
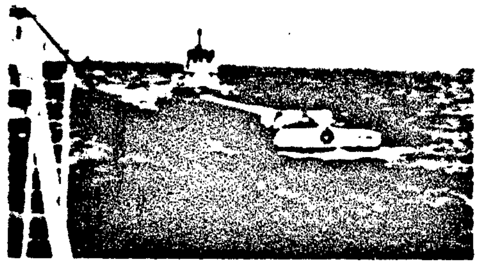
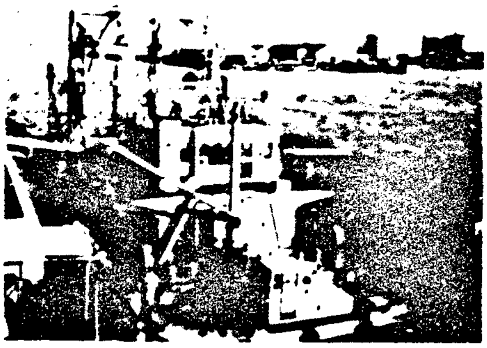


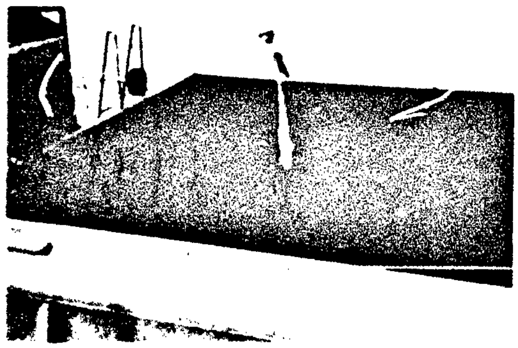
1. The "ShunKai"



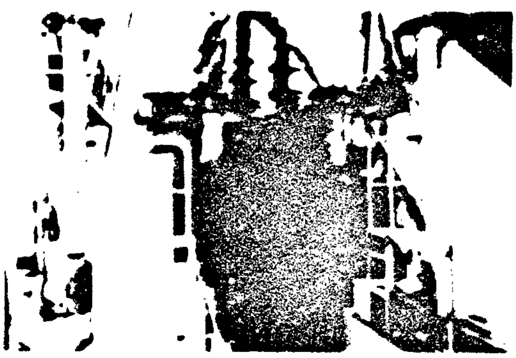
4. Carriage by a pusher boat and a box barge



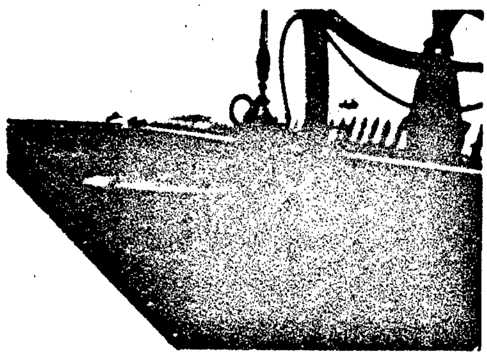
2. Dredging



5. Oil treatment by neutralizing agent

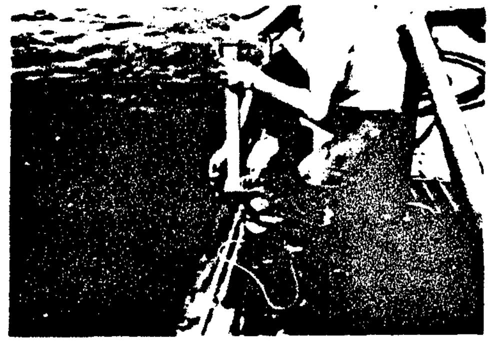


3. Pneuma pump

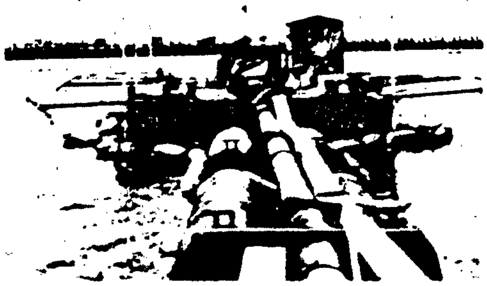


6. Unloading by special pump

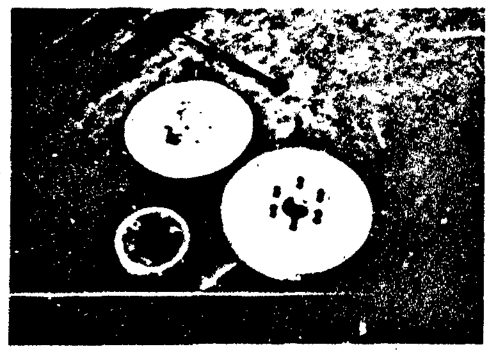
7. View of the disposal site



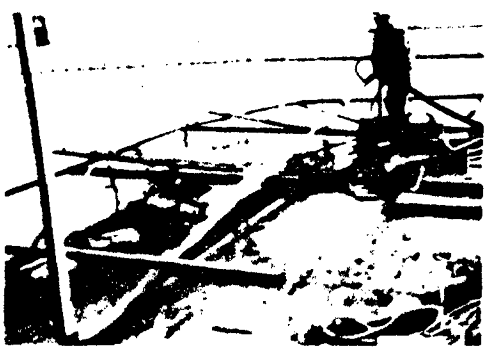
10. Transparency test of water sample



8. Encircled oil fence with curtain



11. New and old plate valve for inlet in a pump body



9. Treatment of floating oil in the disposal site

12. A damaged ball valve for mud delivery

CONSTRUCTIVE USE OF DREDGED SAND

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ABSTRACT

Two obvious opportunities for constructive use of large volumes of dredged sand are beach preservation and offshore bar construction. To date, research has focused on beach preservation. Technology to place dredged sand directly on the beach has been developed and is now routinely used. Technology to place material offshore for distribution on the beach by natural forces has not yet matured. Considerable research designed to define the limiting depths within which natural distribution will occur has been undertaken both in the laboratory and in the field. Some of the most comprehensive work was done by the Corps of Engineers Coastal Engineering Research Center in 1976 and 1978 using a split-hull barge and a split-hull hopper dredge for sand transport and placement. In the 1976 experiment, 27,000 m^3 of sand was placed in a single mound between -2 and -3 foot contours. In the 1978 experiment, almost 34,000 m^3 was placed at three different depths averaging 2.7, 3.6, and 4.7 meters. These experiments generally confirmed the feasibility of beach nourishment by placement of dredged sand in relatively shallow water. To date, little research aimed at the development of technology to construct offshore bars in depths adequate for the operation of medium and large hopper dredges has been undertaken. Little information is available about the stability of such bars, their effect on the shoreline, or their effect on wave climatology.

INTRODUCTION

Background

The construction and maintenance of coastal harbors and navigation channels has always involved dredging of large volumes of material - much of it sand. Over time, the amount of material dredged has steadily increased as the depth demands of shipping have increased. In the United States, sand has long been in abundant supply and readily available from conventional upland sources at a modest cost. Consequently, sand as a natural resource has been taken for granted. For a variety of reasons, sand from conventional sources has become increasingly more expensive and less readily available in recent years. As a

consequence of the decreasing availability from conventional sources and the increasing volume of dredged sand, recognition of the importance of dredged sand as a natural resource has been growing during the past 2 or 3 decades. At the same time, concern about the ultimate consequences of wasting this resource at sea has mounted. Considerable attention has been given - and continues to be given - to constructive use of dredged sand. In the marine environment, the two obvious opportunities for the constructive use of large volumes of dredged sand are beach preservation and construction of offshore bars. Most research and development has focused on technology for beach preservation. Little effort has been made to develop technology for bar construction.

Beach Preservation

Eroded beaches are usually restored by an initial placement of sand to return the beach to a selected pre-existing dimension. The restored beach often continues to erode, necessitating periodic placement of additional sand to nourish the restored beach. The Corps of Engineers is actively engaged in a program of beach restoration and beach nourishment in the United States. Beach restoration is usually accomplished by direct placement of sand on the beach proper. Beach nourishment is usually accomplished by similar placement or by placement of sand to form a feeder beach from which natural forces will distribute sand along the beach to be nourished. For both activities, sand is often mined from offshore deposits by dredges. Beach preservation can be - and sometimes is - combined with harbor or channel dredging to permit constructive use of the dredged sand. Technology to place sand so dredged or mined directly on beaches or feeder beaches is quite well developed. Both hopper and pipeline dredges are routinely used. Direct placement is effective and is a constructive use of the dredged sand resource but economic and other advantages may be realized from offshore placement of nourishment sand. Waves and wave-induced currents active in nearshore waters are a natural transport system that will distribute sand along a shore. Much investigative attention has been devoted to definition and understanding of this littoral process but definition and understanding are still quantitatively imprecise. Effective utilization of the littoral process in beach nourishment actions involving offshore feeder sources requires definition of the seaward limit of the zone within which natural transport success is predictable. Efforts to that end have been made and are continuing. Summarization of the results of those efforts is the primary purpose of this paper.

Offshore Bar Construction

Recent dialogue about constructive use of the dredged sand resource has included offshore bar construction. Although large volumes of sand can be used to nourish and restore beaches, a number of economic and other considerations combine to more or less limit this use to instances where pipeline or small, shallow-draft hopper dredges are used. Medium and large hopper dredges cannot operate within the effective littoral transport zone unless a pump-out terminal with proper approach channel is established. This option is quite often not available and is always relatively costly. Additionally, there are practical

limits to the volumes of dredged sand that can be used to nourish beaches near harbors and channels. There seem to be no practical limits to the volumes of sand that can be used to construct offshore bars in water depths in which medium and large hopper dredges can operate. Such bars would most certainly interact with the physical environment in which they were sited. Precise interactive effects are not readily predictable from present knowledge and understandings but present knowledge and understandings do permit general predictions with considerable confidence. Interactive effects will be subtly rather than boldly expressed and subtlety will increase with increasing depth of water over the bar. Some shoreward movement of sand from the bar may occur but the volumetric rate of movement will be quite low and will be an inverse function of increasing depth. At the depths suited to large hopper dredge operation, losses of sand from the bar are apt to be quite slow or negligible and consequently any changes in configuration will be very gradual. The presence of the bar may alter the wave climate somewhat. In depths suited to operation of large hopper dredges, the amplitude of all but extreme event waves is not likely to be affected but the period of long period waves may be reduced. This and the physical barrier effect of the bar may combine to restrict seaward movement of material eroded from the beach area. Little investigative attention has been given to these and other interactions.

Pertinent Beach Nourishment Research

Several experiments have been conducted to examine the efficiency of beach nourishment from offshore feeder sources. Two beach nourishment projects have been completed in which the nourishment sand was placed offshore.

A two-dimensional laboratory study which simulated small and large storm conditions of the Great Lakes wave climate was reported by Kamphuis and Bridgeman in 1975. This showed that, under the controlled laboratory conditions, sand properly located on the profile and placed at the proper time in the season would move shoreward and accrete to the beach.

Three field experiments were conducted prior to the 1976 and 1978 experiments described later in this paper. Sand placed offshore in the experiments at Long Branch, NJ (Hall and Herron, 1950; Harris, 1954), Atlantic City, NJ (Hall and Watts, 1975), and Santa Barbara, CA (Wiegel, 1964), were not fully successful or conclusive. At Long Branch, 460,000 m^3 of sand placed in 10- to 12-meter water depths either did not move or moved "haphazardly." At Santa Barbara, 153,000 m^3 of sand placed in a 1.5-meter-high mound in 6.7 meters of water showed no significant change in configuration 9 years later. At Atlantic City, sand was placed in 4.5 to 6.1 meters of water but postplacement observations did not develop enough information to evaluate its behavior.

Beaches at Copacabana, Brazil (Vera Cruz, 1972), and Limjford Barriers, Denmark (Mikkelsen, 1977), were successfully mourished from feeder sources placed in water depth of 4 to 6 meters.

In 1976 and 1978, field experiments were conducted by the Corps of Engineers Coastal Engineering Research Center at New River, NC. These are the most comprehensive investigations undertaken to date. The remainder of this paper summarizes those experiments. Detailed reports are in Technical Paper 80-1, Coastal Engineering Research Center, by Robert K. Schwartz and Frank R. Musialowski, and a Technical Paper to be published, Coastal Engineering Research Center, same authors.

1976 EXPERIMENT

Purpose

The experiment was designed to test and evaluate the hypothesis that sand dredged from a coastal inlet and placed seaward of the surf zone will effectively nourish the downdrift beach. The means for doing this became available when the self-propelled split-hull barge, "Currituck," was placed in service in 1975. The "Currituck" is shallow draft and can dump in 2 meters of water. Fully loaded, its capacity is between 200 and 300 m^3. It was loaded by a side-cast dredge. The location for the experiment was New River, NC, which is about 60 km northeast of Wilmington, NC. The beach southwest of the New River Inlet (West Onslow Beach) was the nourishment target. The beach is about 60 m wide, backed by a vegetated foredune, and only slightly developed.

Definitions

The offshore zone extends from the surf zone to the seaward edge of the Continental Shelf. The nearshore zone extends seaward from the shoreline well beyond the surf zone and defines the area of nearshore currents. Nearshore currents comprise the current system caused primarily by wave action in and near the surf zone. The surf zone extends from the limit of wave uprush to the outermost breaker. Nearshore and offshore zones overlap and lack a distinct boundary. The seaward limit of this experiment is within the overlap. In this paper, offshore refers to any point seaward of the surf zone.

Procedures

Placement of sand in the test area began 19 July 1976 and continued for 26 days. The "Currituck" placed a total of 26,750 m^3 along a 210-meter reach between the 1.8- and 4.0-m contours. The tidal range was about 1 m. Monitoring began 7 days before the start of placement and continued 71 days after completion of placement (12 July to 19 October).

Profiles extending across the beach and nearshore zone were measured at 30-m intervals in a 270- × 300-m area. The shore normal dimension (300 m) extended from the base of the foredune some 240 to 270 m beyond MLW to an approximate water depth of 4.5 m below MLW. The beach leg of each profile was measured using standard rod and tape surveying techniques. The seaward leg was measured using a towed, bottom-riding sea sled with mounted stadia board (Musialowski

and Schwartz, 1979). The sled was towed seaward to the outer station on the profile line and then pulled landward by a shore-based winch. Position and elevation data were obtained as it was pulled shoreward. The profile data were used to calculate volumes between adjacent profiles.

Sediment samples were collected from the upper 2 cm of the seabed at 7.6-m intervals along a profile line near the middle of the study area. Current velocity and direction, breaker height and period, angle of wave approach, and wind velocity and direction were measured from 14 July to 16 September using Littoral Environment Observation (LEO) techniques (Bruno and Hippaka, 1973). Aerial photographs were used to document beach and offshore feeder pile configuration and to examine nearshore circulation in the placement area. Several current meter measurements were made to document current distribution.

Physical Environment

Before the experiment, the beach was fronted by a shore-parallel, semi-continuous bar located in the outermost part of the surf zone. The beach and nearshore sands were fine grained (0.14 mm) and well sorted. The tidal range predicted for the study period had a mean of 1.0 m and a spring of 1.1 m.

Breaker heights ranged from about 0.1 m to about 1.6 m and averaged 0.55 m with a standard deviation of 0.26 m. Breaker periods ranged from about 1 second to about 12 seconds and averaged 7.3 seconds with a standard deviation of 1.8 seconds. During the placement period, summer oceanographic conditions prevailed. Breaker heights were usually less than 0.6 m and breaker periods were usually shorter than 6 seconds. Waves generally came from the southerly direction. During the latter part of the experiment, winter oceanographic conditions dominated. Breaker heights were commonly greater than 0.6 m and breaker periods were typically longer than 7 seconds. Winter currents were typically southwest at 23 m per minute whereas summer currents were northeast at 18 m per minute. Currents were wave induced throughout the experiment; the test area was outside the influence of inlet-associated tidal currents.

Results

The mechanics and volumetric rate of placement more or less dictated the creation of separated but very closely spaced rectangular piles of sand arrayed shore parallel with long axes normal to the shore. The individual piles were about 9 x 25 x 1.5 m. Collectively, these piles formed a local shoal which caused waves to deform and break. The more seaward parts of the shoal were subjected to less wave breaking than were the more landward parts because the water there was deeper over the shoal. In the short term, the wave and current reworking of the shoal coalesced the individual piles into a generally shore parallel bar seaward of the naturally occurring surf zone bar. The bar thus formed migrated shoreward but never reached the surf zone bar. The migration rate was sporadic and reflected the degree of wave activity. As the bar neared the surf zone bar, it was either eliminated or became rounded and much reduced in relief. During the last month of the experiment when storm conditions prevailed, the profiles in the placement area accreted in the offshore zone. Accretion was also evident on profiles outside the placement area indicating

that this accretion was a redistribution of sediments independent of the experiment. The surf zone bar landward of the placement area eroded or was displaced landward. At the same time, the surf zone trough filled and became an extension of the foreshore. Adjacent to the placement area, the surf zone trough also filled but the surf zone bar remained stationary.

During the first month after placement was completed, a large decrease in volume in the offshore zone was noted. About 75 percent of the placed sand was apparently removed during this period. Adjacent to the updrift side of the placement area, a slight increase in volume was measured. Adjacent to the downdrift side of the placement area a substantially larger volume gain was measured. Volume changes in the inshore zone were similar but of lesser magnitude.

1978 EXPERIMENT

Purpose

In the 1976 experiment, placement was essentially in a single mound at a single depth. It showed that the sand so placed was distributed by littoral processes. The 1978 experiment was designed to test and evaluate the effects of increased placement depth on postplacement transport. To do this, placement in several mounds and at different depths was planned. The 1978 experiment differed from the 1976 experiment in 3 important aspects other than placement patterns. The 1978 experiment was designed to continue for at least 12 months. The "Currituck" was modified by the addition of drag heads and pumps and became a small hopper dredge instead of a self-propelled barge. The Coastal Research Amphibious Buggy (CRAB) replaced the less versatile sea sled as a surveying vehicle. The 1978 experiment, like the 1976 experiment, was conducted at New River, NC. West Onslow Beach remained the nourishment target.

Definitions

The terms used in discussing the 1978 experiment have the same meanings as for the 1976 experiment.

Procedures

Sand was placed in three different water depth locations during July and August. The average water depths at these locations were 2.7 m, 3.6 m, and 4.7 m. A total of 33,900 m^3 was placed in 35 days. Monitoring began in June.

Data collection devices were mounted on the CRAB which carried a horizontal positioning system interfaced with a shore-based minicomputer. Elevations were measured by a shore-based level and the CRAB stadia board. Both position and elevation data were recorded on tape. This semi-automated data collection

system provided significant in-field data reduction, allowed real time tracking of the vehicle, and permitted real time analysis of profile shape. The quality of data benefited accordingly.

Profiles were measured in the same pattern as in the earlier experiment in a 490-m x 450-m area.

Vibracores were taken along selected shore normal transets using a CRAB-mounted portable vibracoring system (Lanesky, Logan, Brown, and Hine, 1979). Divers collected sediment samples from the upper 20 cm of the seabed along 3 profile lines.

Physical Environment

The physical environment was essentially the same as for the 1976 experiment.

Results

As in the 1976 experiment, sand was placed in rectangular piles about 9 m x 25 m x 1.5 m. At shallow water locations, the piles were grouped as in 1976 and in short term coalesced to form pseudo bars. At deeper water locations, piles were placed on top of one another as well as side by side. This placement produced 2.5-m-high mounds with water cover of about 0.6 m. Wave and current reworking of all three bars occurred as in 1976 and with similar results. The early volumetric loss rate measured from inshore was very comparable to that measured in 1976. The loss rate decreased with time but movement out of the placement area was still evident a year after placement. The bar formed by placement in the intermediate depth area also migrated landward and underwent relief reduction. Both were at somewhat lower rates than the shallow depth bar and both decreased with time. The bar remained a distinct identifiable feature for a longer time period than did the inshore bar. The bar created by placement in the greatest water depth area migrated landward at a slower rate than either of the two inshore of it and the volumetric loss rate from it was markedly less than for the other two. No lateral movement of this bar was discernible during the first five months after placement.

In the test area as a whole, the bars formed by sand placement migrated landward and laterally albeit at different rates. This migration was most evident during the first 6 months of the experiment. At the same time, the volume of sand contained in the bars diminished. No seaward displacement occurred. These observations were confirmed by textural changes in bottom sediments in the area. The rate at which the bars were modified was greatest for the most landward bar and lowest for the most seaward bar. The highest initial volume changes were at locations in or near the breaker zone.

CONCLUSIONS

Shallow draft, split-hull hopper dredges can place dredged sand just seaward of the surf zone so that it will move onto and along the beach. Such dredges can also maintain shallow-draft navigation channels including entrance channels through tidal inlets. Shallow-draft, split-hull hopper dredges are therefore quite competent for sand bypassing at tidal inlets and for the constructive use of dredged sand in beach preservation activities. No further laboratory or field experiments seem warranted but large-scale demonstration projects should be planned. Such demonstration projects should be monitored until the technology is judged mature.

Demonstration of the effectiveness of shallow water placement of dredged sand for constructive purposes is a partial answer to concern about wasting an important natural resource. The larger question about constructive use of sand dredged by medium and large hopper dredges remains. Offshore bar construction should now be addressed by a large-scale demonstration. That demonstration should be designed to determine whether the sand remains where placed, whether the bar modifies the wave and current climate, and whether the bar modifies shore normal sediment transport patterns.

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RECLAMATION WITH SOFT SEA BOTTOM SEDIMENTS

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ABSTRACT

When dredging soft sea bottom sediments, it is important to estimate the suspended solids (SS) concentration in the effluent from the overflow weir. In some cases, special effluent treatment methods must be adopted to meet the SS concentration level and environmental quality standard. One effective means for reducing the SS concentration level of the effluent is to employ the SS removal ability of the diked containment area through the hydraulically appropriate layout of inlet/outlet or baffle walls in the containment area. To estimate the effluent SS concentration and to evaluate the sedimentation promotion, model tests were performed on the influence of the SS concentration in the influent and on the effect of inlet/outlet layouts and installation of baffle walls in the containment area.

In model tests on the influence of the SS influent concentration on that of the effluent, fly ash and Kibushi clay were used as testing materials in 20 cases where the influent SS concentration was varied 0.2 - 100 g/ℓ and the number of steps of overflow rate was 2. The SS runoff rate tends to decrease with the increase of influent SS concentration, and an experimental equation of SS runoff rate was obtained. Effluent SS concentration had the peak value at around 10 g/ℓ of influent SS concentration.

In the model tests on the sedimentation promotion effect of the inlet/outlet layouts, fly ash was used as testing material in 30 cases where the concentration was 10 g/ℓ and the number of types of layout and structure was 11. The four steps of overflow rate covered 0.139×10^{-5} to 1.39×10^{-5} m/sec. The layout types were divided into two groups according to their characteristics. One group showed the value of SS concentration smaller than c_q, calculated from the formula of ideal settling basin; the other group showed a value larger than c_q. Good sedimentation promotion effect was obtained even in the simple types.

In the model tests on the sedimentation promotion effect of baffle walls installation in the containment area, fly ash was used as testing material,

at a concentration of 10 g/ℓ, in 30 cases. The number of types of baffle walls installation was 10, and overflow rate was as before. In the small overflow rate range, SS concentration of effluent in any baffle wall installation type was approximately equal to that of the ideal settling basin. However, in the large overflow rate range, a high sedimentation promotion effect was observed in the submerged cross dike.

INTRODUCTION

When pump dredged sediments are disposed into the diked containment area, water pollution will not occur around the containment area by the effluent if dredged sediments are good quality sand. However, attention must be paid when the dredged material is small in particle size like silt and clay and polluted by organics or toxic matters. When an adverse impact on fishery may be expected, the selection of dredging period, restriction on the operation of pump dredge, or effluent treatment must be considered. In all cases it is important to know the relationships between effluent quality and dredged material, reclamation area, and operating condition. In this report, the authors tried to investigate SS that did not settle in the containment area and ran off with the effluent. The SS concentration correlates not only with turbidity, but also with quantity of toxic matters in the reclamation of bottom sediments containing toxic matters. Therefore, SS concentration is a basic and useful measure of water quality.

In the field of water works and sewage treatment, SS removal in the settling basin has been studied and many references are available (1 - 3, 8, 9). These basins, however, are fairly different from the diked containment areas for reclamation with dredged material, so only the basic ideas of the literature can be useful, but this is not sufficient. For this reason, as for soil particle settling in the containment area, more studies from a different viewpoint than water works and sewage settling basin are needed (4 - 6).

The main features of containment areas are as follows:

a. Various shape, area, depth of containment areas.

b. High SS concentration of influent.

c. Inlet (influent loading pipe) and outlet (effluent weir) are generally small and can be considered as points.

d. Water depth of the pond is small relative to the water area.

e. Quality and quantity of influent are not uniform.

f. Water depth and water area decrease with the process of reclamation.

g. In many cases influent loading rate (overflow rate) is small compared with other water treatment, but influent quantity is large.

Some of these features appear strong or weak in each reclamation work, so the phenomena are generally complicated and difficult to explain. In other words, there may be cases in which the phenomena appear in one work, but not in another, or the same SS treatment method is effective in one work, but not effective or detrimental to another work.

The authors of this paper are studying the estimation of the effluent SS concentration and the promotion of the removal effect of soil particles in the containment area. This report introduces model tests conducted to explain the relationships between influent SS concentration and that of effluent, SS removal effect promotion by inlet/outlet layout types and structures (11, 12), and SS removal effect promotion by the installation of baffle walls in the containment area (7, 10). These relationships are compared with the effluent SS concentration. This study is now under way, and the analysis may not be sufficient and the model test method may need further consideration, but qualitative results were obtained and are presented herein.

MODEL TESTS

Similarity of Model

Model test results are significant and easy to transform if the similarity law between real and model is clear. In model tests that treated fluids like water, tests where there was no free water surface (a pipeline) were conducted based mainly on Reynolds law, and tests where there were effects of free water surface (ports and harbors) were based on Froude's law. But, in model tests of containment areas neither of these similarity laws is suitable. Water surface gradient by gravity cannot be simulated using the similarity law of Reynolds, and flow pattern like swirl caused by viscosity cannot be simulated when using the similarity law of Froude. In addition to these hydromechanical problems, the modeling of settling particles is one of the difficulties encountered in model tests of settling basins. In some model tests on ports and harbors, settling particles of modified specific gravity can be used to suit the similarity law of Froude. On the other hand, there is the method where the real settling particles are used for simplification of testing. In the latter case, settling phenomena will be distorted based on Reynolds' or Froude's laws if the model settling basin is geometrically similar to the real one. For this reason, the concept of an ideal settling basin perpendicular in two dimensions is introduced, where the model settling phenomenon is similar to the real one. This is called "similarity of overflow rate" and is used widely in the water treatment field. In this, the hydromechanical aspect decreases because the settling phenomenon is treated as ideal, but the velocity term in the model is equal to that in the real. It is smaller than that by Reynolds' law and larger than that by Froude's law, so the value of the velocity term by the law of overflow rate lies between the two laws. Models in this paper are not the model of a particular real containment area. Comparisons among many test cases are shown, where model specification was determined mainly by similarity of overflow rate.

Experimental Equipment

The model containment area is 6.8 × 2.5 × 1.0 m (Figure 1). Water depth was usually 0.1 m in the model tests. The velocity of influent at the inlet

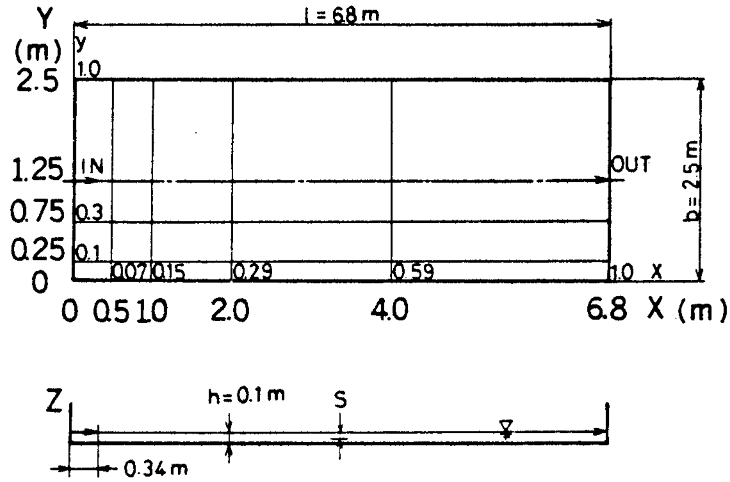

Figure 1. Model containment area

pipe of the real ν_{in}' (noted ' in case of real) was assumed to be 3 m/sec. The basic shape of inlet pipe was a round tube, and the outlet was a rectangular weir. The inlet velocity of the model ν_{in} was determined by the similarity law of Froude; D was determined according to the overflow rate of each test case; and the static head of the overflow weir H was also determined according to the overflow rate. The model basin is shown in Figure 1, and the plan layout of experimental apparatus is shown in Figure 2. When the model scale ratio is assumed to be 1/100, the main dimensions of the real containment area are shown in Table 1.

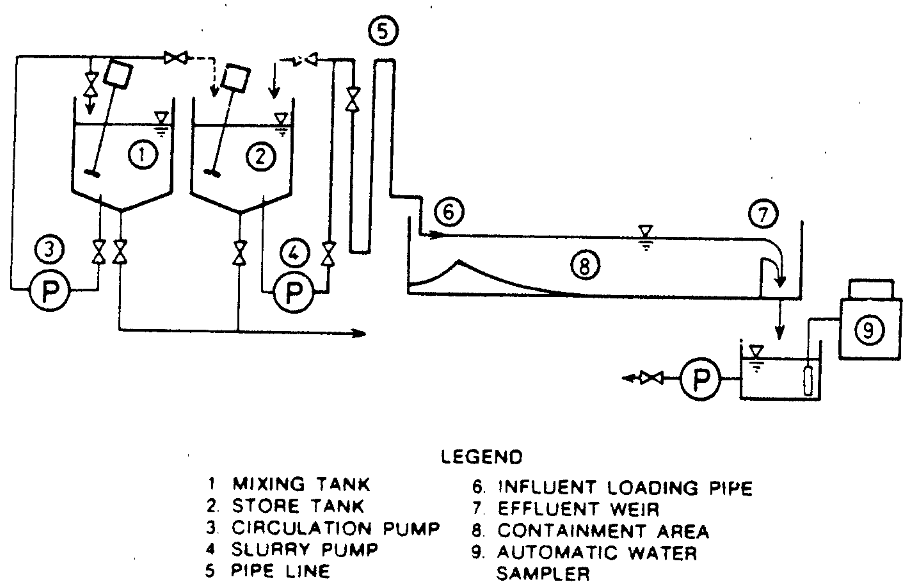

Figure 2. Experimental apparatus

Slurry was made in the mixing tank (0.6 m^3) by adding testing material and fresh water, and pumped to the store tank. Slurry in the store tank (0.6 m^3) with a stirrer was discharged into the containment area at a specified loading rate and velocity. The containment area was initially conditioned by filling with fresh water up to the top level of the effluent weir and allowing to stand.

Testing Material

In model tests on particle settling, materials with a different specific gravity from that of the real ones may be used. But modeling of the particles is difficult, especially in cases where the particle size or the settling velocity has a range of distribution; in these cases, real particles were used in the model tests. These experiments used no particular type of real soil particle; in cases where the settling velocity of the particles is distributed, fly ash and Kibushi clay, which are easy to handle in model tests, were used as testing materials.

The specific gravity of a fly ash particle is 2.1 and in it different colored particles can be observed. Kibushi clay particles are 2.6 in specific gravity and homogeneous in color. Figure 3 shows the cumulative particle-size distribution of both testing materials by Coulter Counter method. Volume per unit weight of each material in water differs by the quantity of the sample. Figure 4 shows the results of the column tests in which 100 g of testing materials was added to water to make a 1-ℓ mixture. After 24 hours of line settling, the volume per unit weight of testing material was 1.23 mℓ/g for fly ash and 2.43 mℓ/g for Kibushi clay.

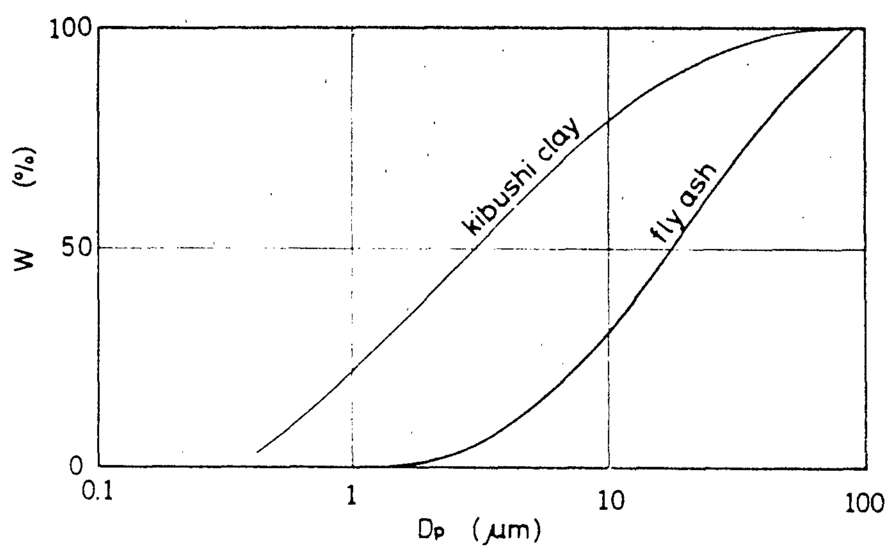

Figure 3. Cumulative particle size distribution

Table 1. Main dimensions of the model and the real containment area

model ℓ = 680 cm b = 250 cm B = 4 cm ν_{in} = 30 cm/sec	water depth	h cm	10			
	influent loading rate	Q cm^3/sec	Q10 = 236	Q5 = 118	Q2 = 47.2	Q1 = 23.6
	static head of the overflow weir	H cm	2.2	1.4	0.7	0.5
	diameter of the inlet pipe	D cm	3.2	2.2	1.4	1.0
	overflow rate	V_o m/sec	1.39×10^{-5}	0.694×10^{-5}	0.287×10^{-5}	0.139×10^{-5}
real (assumption) ℓ' = 680 m b' = 250 m B' = 4 m ν_{in}' = 3 m/sec	water depth	h' m	10			
	influent loading rate	Q' m^3/sec	2.36	1.18	0.472	0.236
	static head of the overflow weir	H' m	0.486	0.295	0.160	0.101
	diameter of the inlet pipe	D' m	1.00	0.708	0.448	0.317

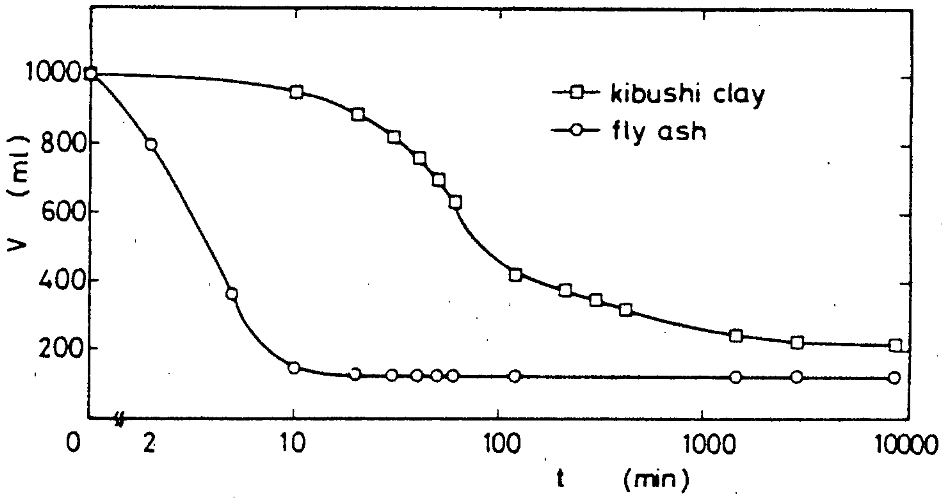

Figure 4. Results of the column tests

Particle settling velocity is affected by the concentration of the particles and decreases with the increase of the concentration of the particles (13). Settling tests were conducted to investigate the settling characteristics of the testing materials using a settling column 30 cm in diameter and 100 cm in height. After stirring the mixture, the water was sampled at certain time intervals at a fixed point. Figure 5 shows a plan of the settling

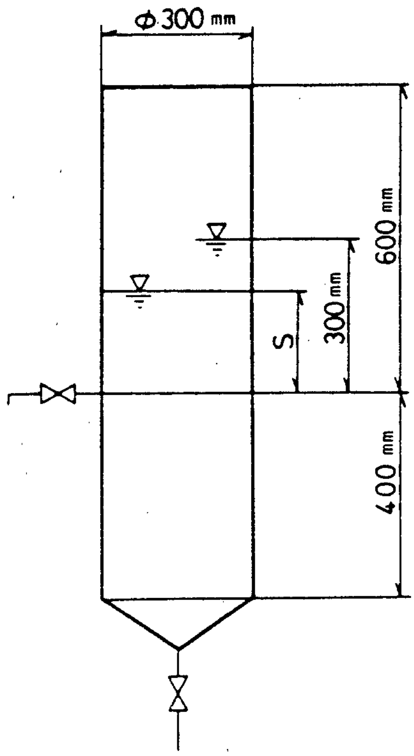

Figure 5. Settling column

column. Initial sampling depth is 30 cm, and sampling quantity is 0.5 - 1 ℓ at a time, so the sampling depth S gradually decreases.

Figures 6 and 7 show the solids concentration in the sample water in relation to the initial concentration of slurry. For fly ash with an initial concentration C_o of 0.1 and 1 g/ℓ, the concentration of the sample C decreases gradually with the lapse of time. Plus, C is higher for 1 g/ℓ C_o than for 0.1 g/ℓ C_o. However 10 g/ℓ C_o represents line settling and C becomes lower than that for 1 g/ℓ C_o after a certain amount of time. This tendency is observed more clearly for 100 g/ℓ C_o, and C becomes lower in the clear water above the boundary line than that for 1 and 10 g/ℓ C_o and is about the same value as 0.1 g/ℓ C_o. A similar tendency was observed for Kibushi clay, but the line settling velocity was smaller compared with fly ash.

Figures 8 and 9 summarize these results in the form of cumulative settling velocity distribution. In case of fly ash, it represents line settling at the initial concentration more than 10 g/ℓ, and when initial concentration is less than 1 g/ℓ, where the settling mechanism is discrete settling, it makes no difference in settling velocity distribution.

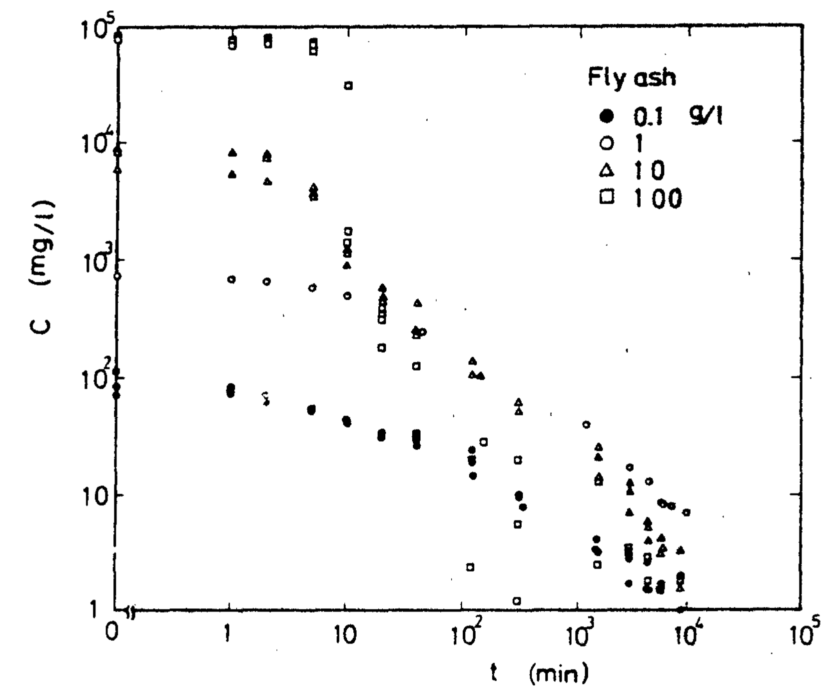

Figure 6. Solids concentration in the sample water, fly ash

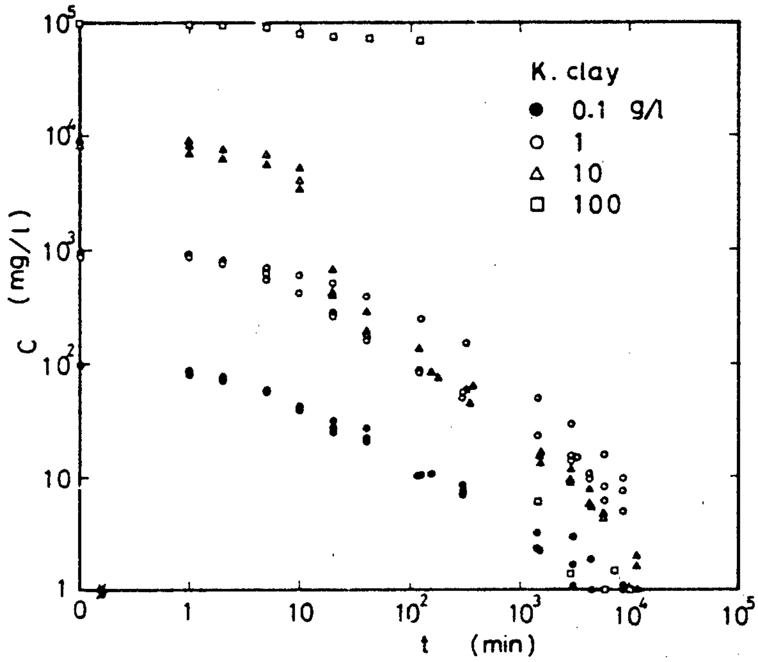

Figure 7. Solids concentration in the sample water, Kibushi clay

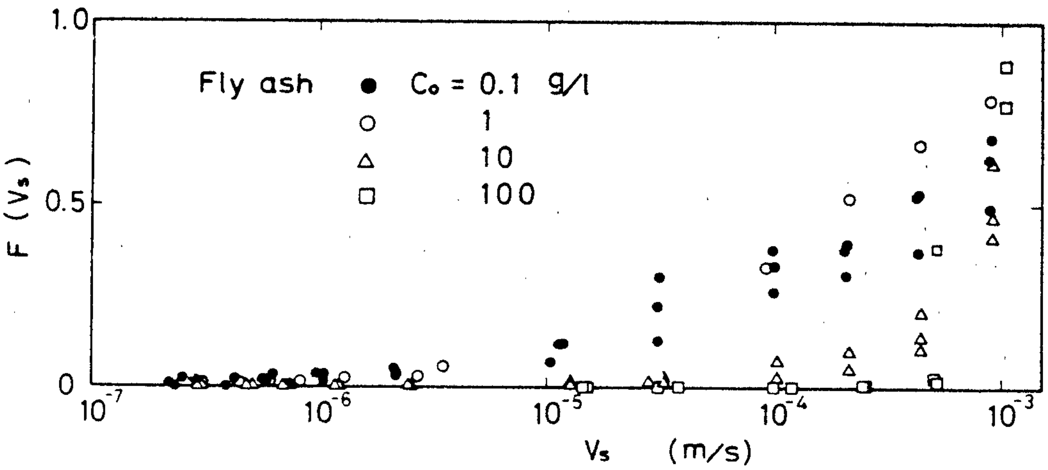

Figure 8. Cumulative settling velocity distribution, fly ash

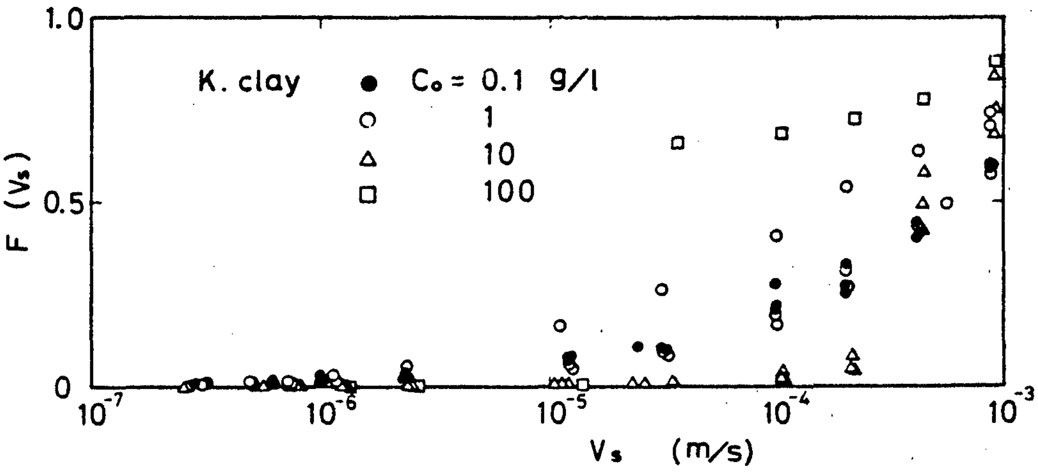

Figure 9. Cumulative settling velocity distribution, Kibushi clay

Kibushi clay (Figure 9) shows almost the same characteristics at a C_o of 0.1 and 1 g/ℓ, but the settling velocity seems to become larger at 10 g/ℓ C_o. For 100 g/ℓ C_o, however, the cumulative distribution curve varies sharply at line settling velocity so the weight percentage of the particles whose velocity is larger than line settling velocity becomes smaller and also the weight percentage of the particles whose velocity is smaller than line settling velocity also becomes smaller.

Based on the cumulative settling velocity distribution shown in Figures 8 and 9, SS runoff rate in an ideal quiescent settling basin was calculated using the formula of Hazen and Camp (1), and that in completely mixing settling basin was calculated using the formula of Hazen and Molina (3). These results are shown in Figures 10-15. Here, SS runoff rate c is the

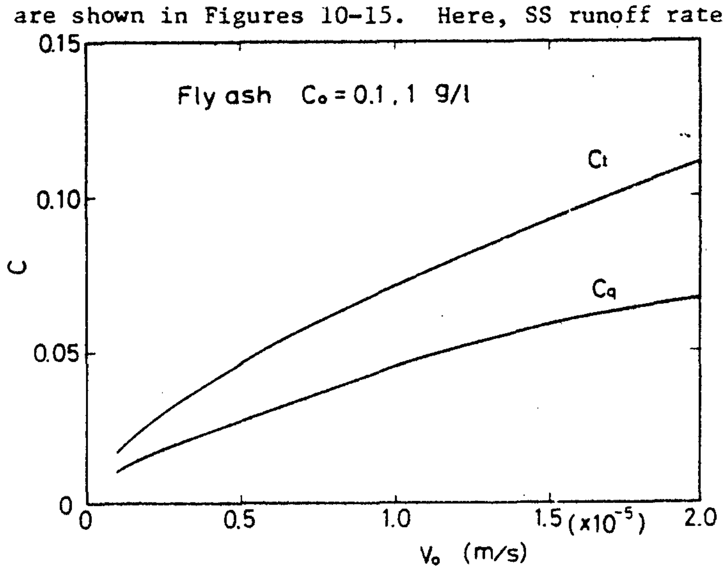

Figure 10. Fly ash, C_o = 0.1,1 g/ℓ

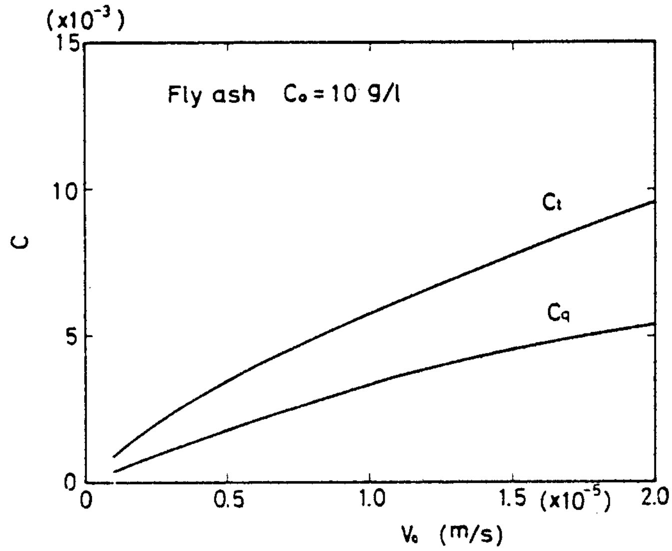

Figure 11. Fly ash, C_o = 10 g/ℓ

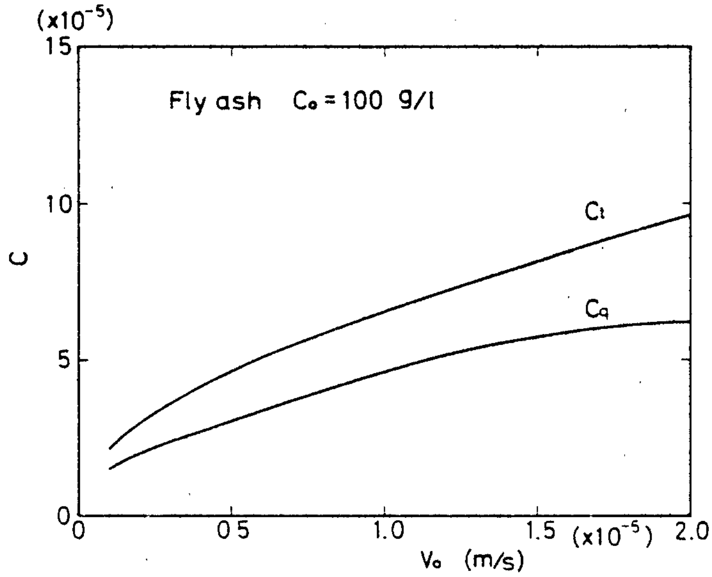

Figure 12. Fly ash, C_o = 100 g/ℓ

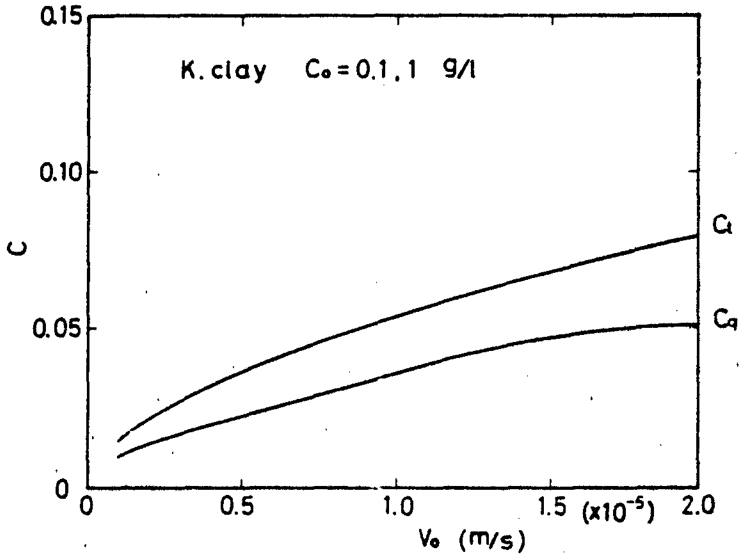

Figure 13. Kibushi clay, C_o = 0.1,1 g/ℓ

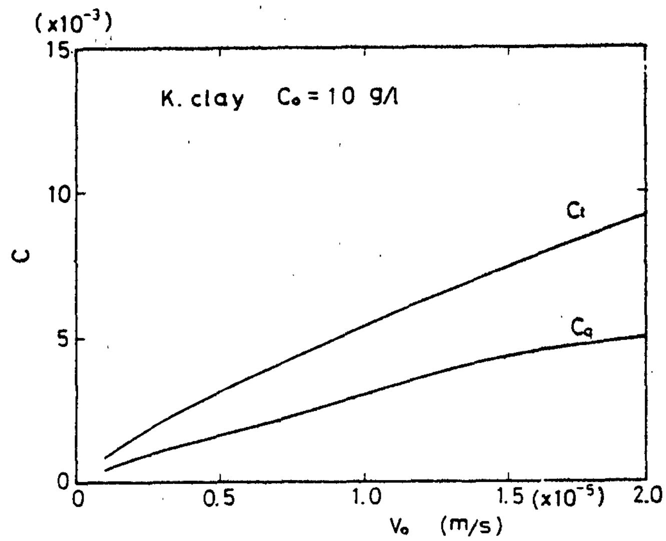

Figure 14. Kibushi clay, C_o = 10 g/ℓ

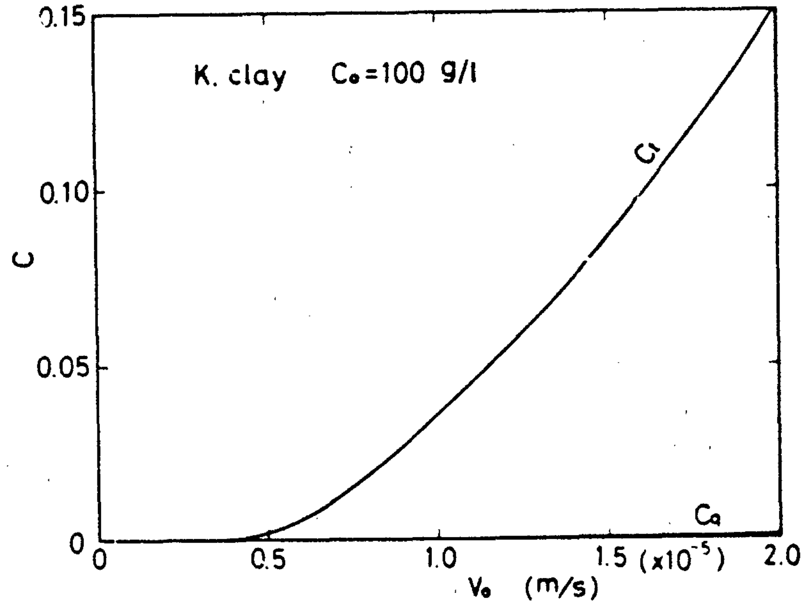

Figure 15. Kibushi clay, C_o = 100 g/ℓ

ratio of the effluent concentration C and the influent concentration C_o, and the relation to removel ratio r is as follows:

$$c = \frac{C}{C_o}, \quad c = 1 - r \tag{1}$$

The runoff rate c_q (ideal quiescent) and c_t (completely mixing) can be obtained by following equations:

$$c_q = \frac{1}{V_o} \int_0^{V_o} F(v_s) dv_s \tag{2}$$

$$c_t = \frac{1}{V_o} \int_0^{\infty} F(v_s) \cdot e^{-v_s/V_o} dv_s \tag{3}$$

where

V_o = overflow rate, m/sec

v_s = settling velocity of particle, m/sec

$F(v_s)$ = cumulative settling velocity distribution

For fly ash, SS runoff rate decreases as the influent concentration increases as shown in Figures 10-12. For Kibushi clay, the same tendency as fly ash can be seen for c_q, but a c_t of 100 g/ℓ C_o is larger than that of 10 g/ℓ C_o.

Experimental Parameters and Variables

In these tests, the authors intended to investigate the effect of the concentration in the slurry influent on that in the effluent, and to compare the effect of sedimentation promotion among the different layout types of inlets/outlets, and the effect of sedimentation promotion by the installation of baffle walls in the containment area. For this reason, only one type of containment area was used. The influent loading time of duration was 7 hours continuously.

In tests to investigate the relation between the influent concentration and the effluent concentration, influent concentration was varied from 0.2 to 100 g/ℓ, where overflow rate and solid material were parameters. The number of steps of overflow rate was two; soil materials were fly ash and Kibushi clay. In other tests influent concentration C_o was 10 g/ℓ.

Water depth of the containment area h did not affect effluent concentration in the ideal basin under the conditions that the overflow rates were the same among cases and that resuspension of sedimented particle did not occur. However, in preliminary model tests on type A layout (see Figure 21), the effect of water depth was observed. When the water depth ranged from 5 to 20 cm, there was no remarkable difference among the solids concentration in the effluent, but in the range of 50 to 80 cm, a decrease in concentration was clear. For this reason and for convenience of testing, h was set at 10 cm.

Influent velocity at the end of the influent loading pipe v_{in} was 3 to 5 m/sec in general. In these tests, it was assumed to be 3 m/sec. From the management of water quality point of view, it is reasonable to make influent velocity smaller for reclamation of soft bottom materials. Though it is not yet clear theoretically how to scale v_{in} in model tests, scaling was selected using the similarity law of Froude, taking into account descending particles and slurry stream from inlet pipe and density current around the inlet. As a result of preliminary tests, SS runoff rate decreased about 15% at 5 cm/sec v_{in} and increased about 10% at 1 m/sec v_{in} compared with 30 cm/sec v_{in}.

In the model tests, as the influent flowed into the containment area, which was already full of fresh water, quantity and concentration of the effluent varied as shown in Figure 16. The representative value of SS concentration in effluent was a mean value after the appearance of steady-state of the effluent.

TEST RESULTS

Effect of Influent Concentration

There were some cases in which the effluent concentration increased gradually throughout the testing period when influent concentration was relatively low, or the effluent concentration increased gradually after [illegible] steady-state. Figures 17-20 summarize the relationship between effluent concentration and influent concentration based on the value at the end [illegible]

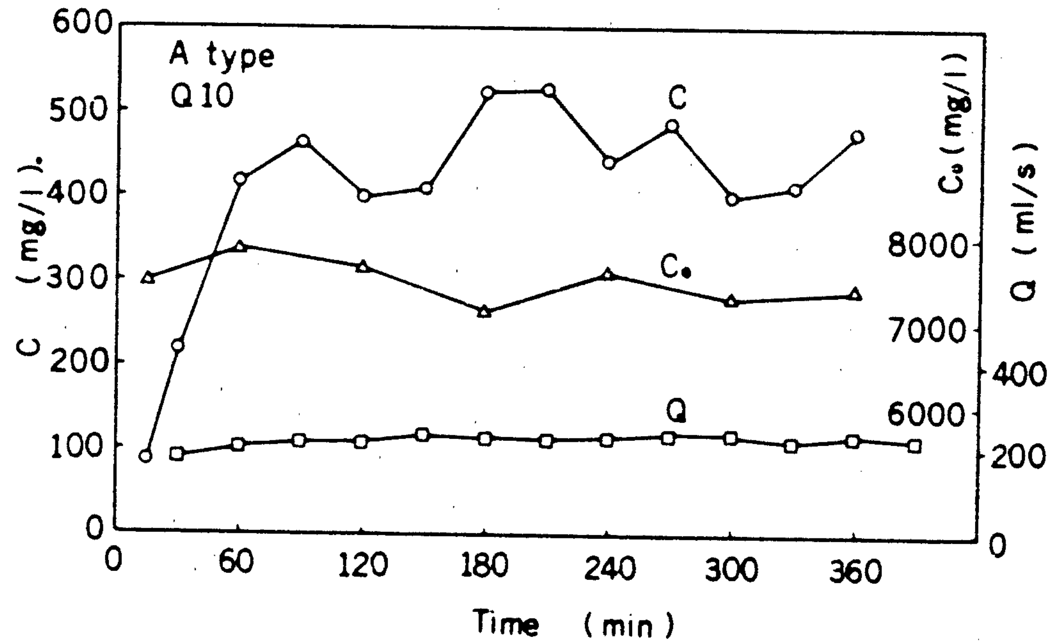

Figure 16. Example of test data

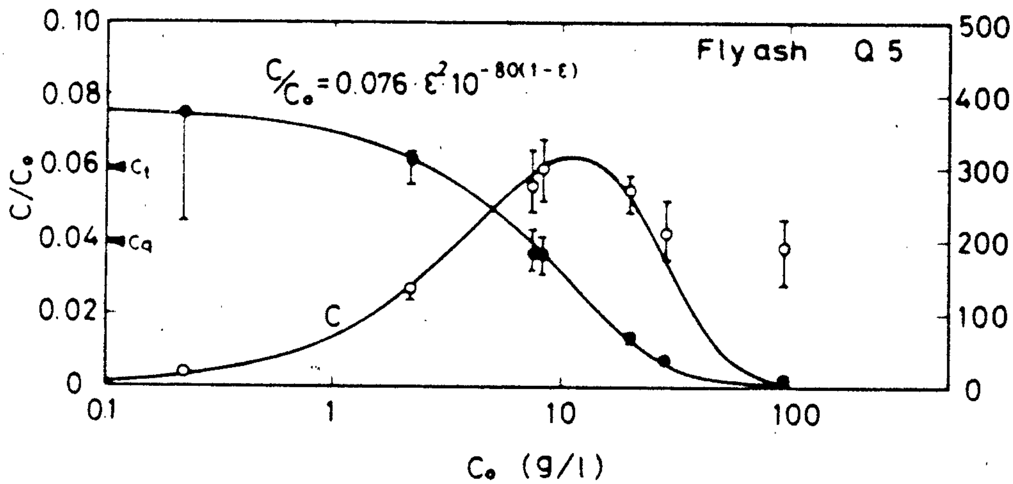

Figure 17. Effluent concentration and runoff rate, fly ash Q5

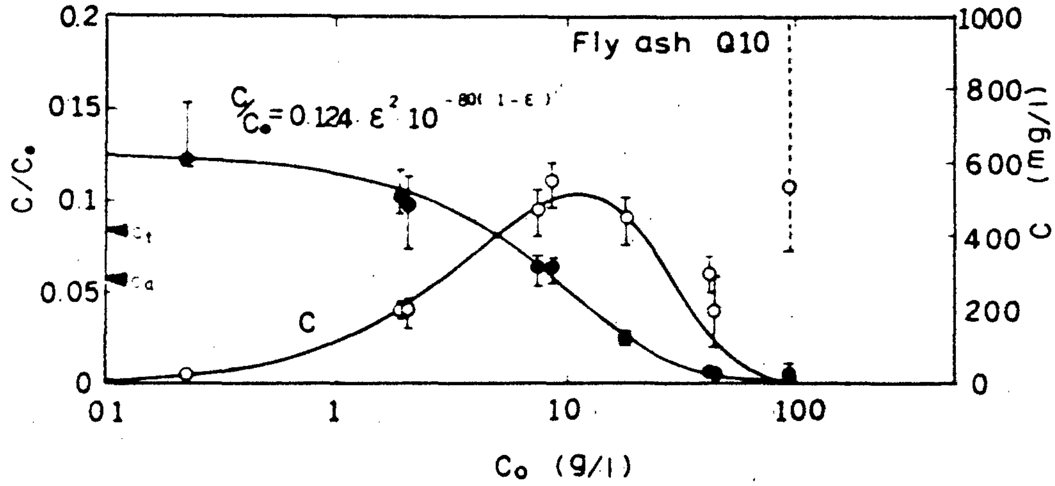

Figure 18. Effluent concentration and runoff rate, fly ash Q10

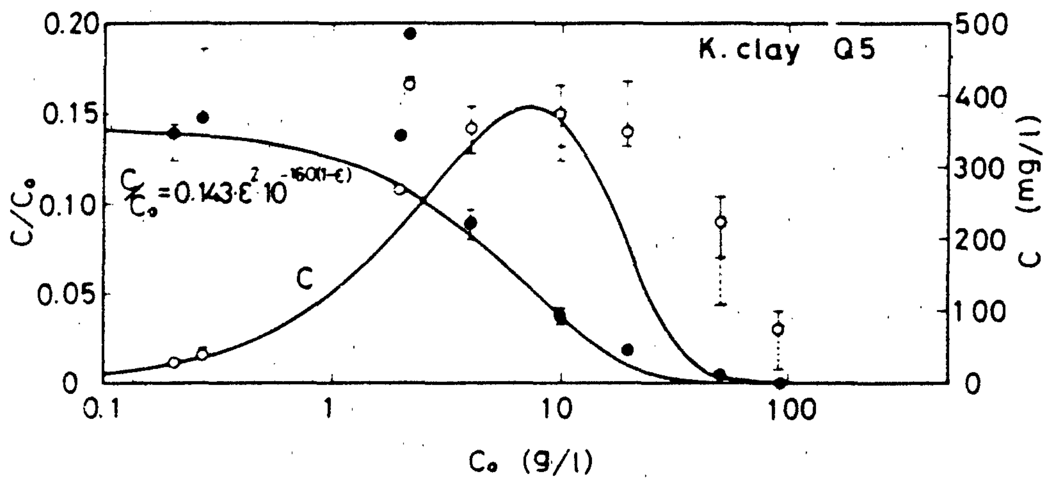

Figure 19. Effluent concentration and runoff rate, Kibushi clay Q5

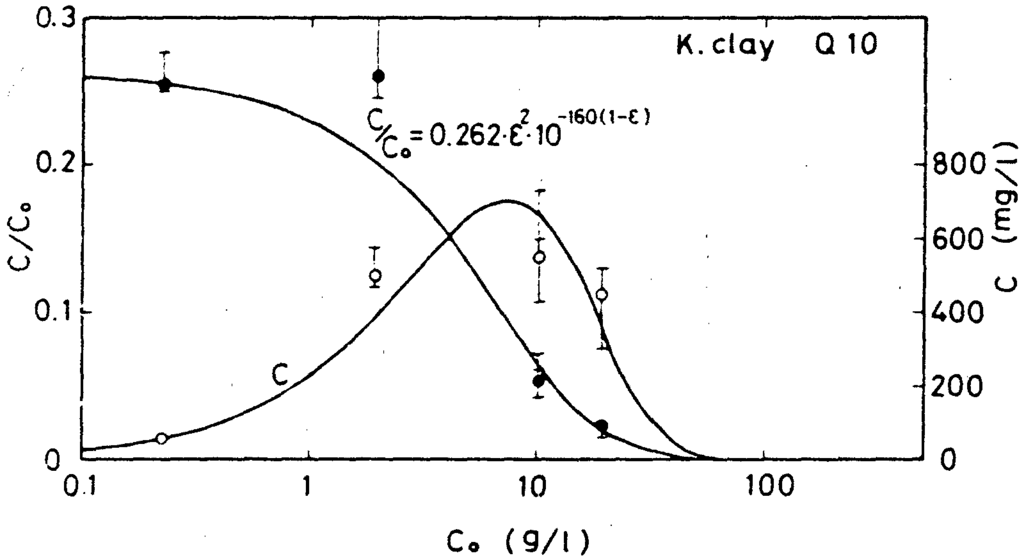

Figure 20. Effluent concentration and runoff rate, Kibushi clay Q10

in the former case, and the mean steady-state value in the latter case. From these results, solids runoff rate C/C_o decreases as the influent concentration C_o increases, and it can be represented as follows:

$$C/C_o = a \cdot \varepsilon^2 \cdot 10^{-b(1 - \varepsilon)} \tag{4}$$

where a and b are coefficients that depend on soil materials and overflow rate; ε is void ratio and is defined as follows

$$\varepsilon = \frac{V - V_s}{V}$$

$$V_s = \omega_s/\gamma_s$$

$$C_o = \omega_s/V$$

$$\therefore \quad \varepsilon = 1 - C_o/\gamma_s \tag{5}$$

where

V = volume of influent slurry

V_s = volume of solid particle

ω_s = weight of solid particle

γ_s = weight of solid particles per unit volume

C_o = solids concentration in influent

On the other hand, effluent concentration C is expressed by the following formula from Equation 4:

$$C = C_o \cdot a \cdot \varepsilon^2 \cdot 10^{-b(1 - \varepsilon)} \qquad (6)$$

Equation 6 has a peak value, and the value of C increases until a certain point of C_o and then decreases with the increase of C_o as shown in Figures 17-20. Test results showed a larger value of C than the value from Equation 6 in the range of C_o larger than the value at which C showed peak value, but those values are less than or equal to the peak C value.

For fly ash, the value of coefficient a is 0.076 and 0.124 at influent loading rate Q5 and Q10, respectively, and coefficient b is 80 in both cases. Equation 6 follows well the values of C obtained by tests in the range of C_o less than 20 g/ℓ, but after that it gives less value than the value of tests. This is especially true for Q10, where the water path varied greatly with the progress of reclamation; therefore, solids concentration in the effluent varied greatly.

For Kibushi clay, the value of coefficient a is 0.143 and 0.262, respectively, and b is 160 in both cases. Model test became unstable from the viewpoint of reappearance and the test res[illegible]differed from Equations 4 and 6 when C_o was approximately 2 g/ℓ. [illegible] of C obtained by the tests was greater than the value from Equation 6 in the range of greater C_o, as in the case of fly ash, but the difference was smaller than that for fly ash and it decreased with the progress of reclamation.

Upon comparing these results with the SS runoff rate calculated from the settling velocity distribution by settling column tests, several items became clear. For fly ash, SS concentration in effluent of model tests is near the value of c_t in the range of C_o less than 1 g/ℓ (but the value is greater than c_t in the range of C_o greater than 10 g/ℓ). For Kibushi clay, almost the same tendency can be seen, but only for 100 g/ℓ C_o is the calculated value of c_t very large and becomes larger than the test results.

Comparison Among Inlet/Outlet Layout Types

Sedimentation promotion effect by inlet/outlet layout and those structure types were compared by SS runoff rate in the effluent. Each layout type is shown in Figure 21 and their structure is shown in Figure 22. Impractical ones can be seen among these types, but they were adopted for purposes of comparison. As for the inlet, type J is one in which the pipe is closed at the end and cut at the upper part. In type L, the pipe is set downward and the influent is converted to radial direction by a baffle plate located under the pipe. In type K, the inlet pipe is supported at the bottom of the basin. In other types the inlet pipe is supported at the water surface. As for the effluent weir, H is the cross-diked weir and the others are rectangular weirs. Test results are shown in Figures 23 and 24.

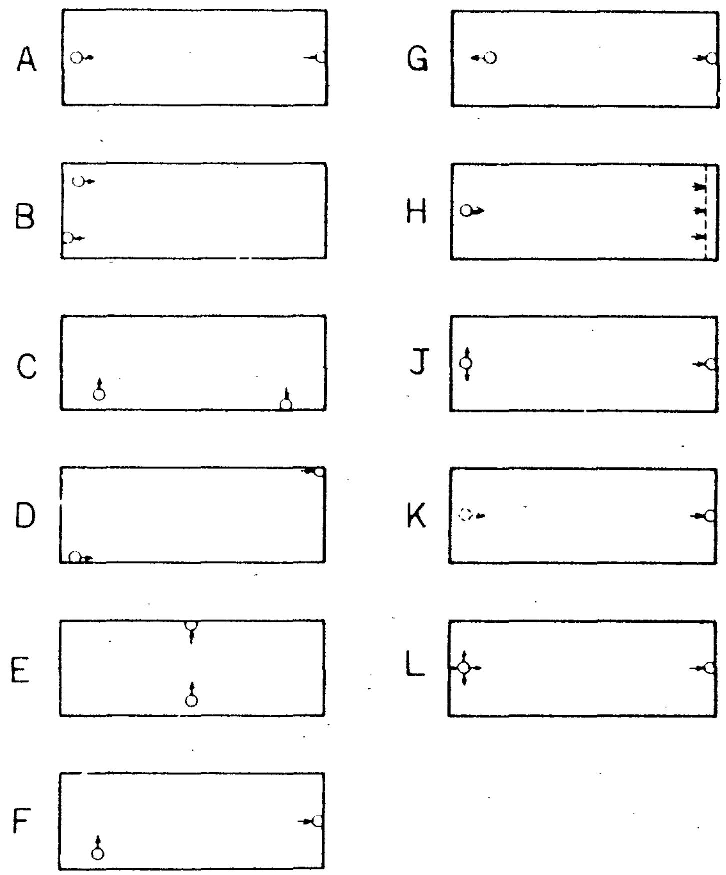

Figure 21. Inlet/outlet layout types

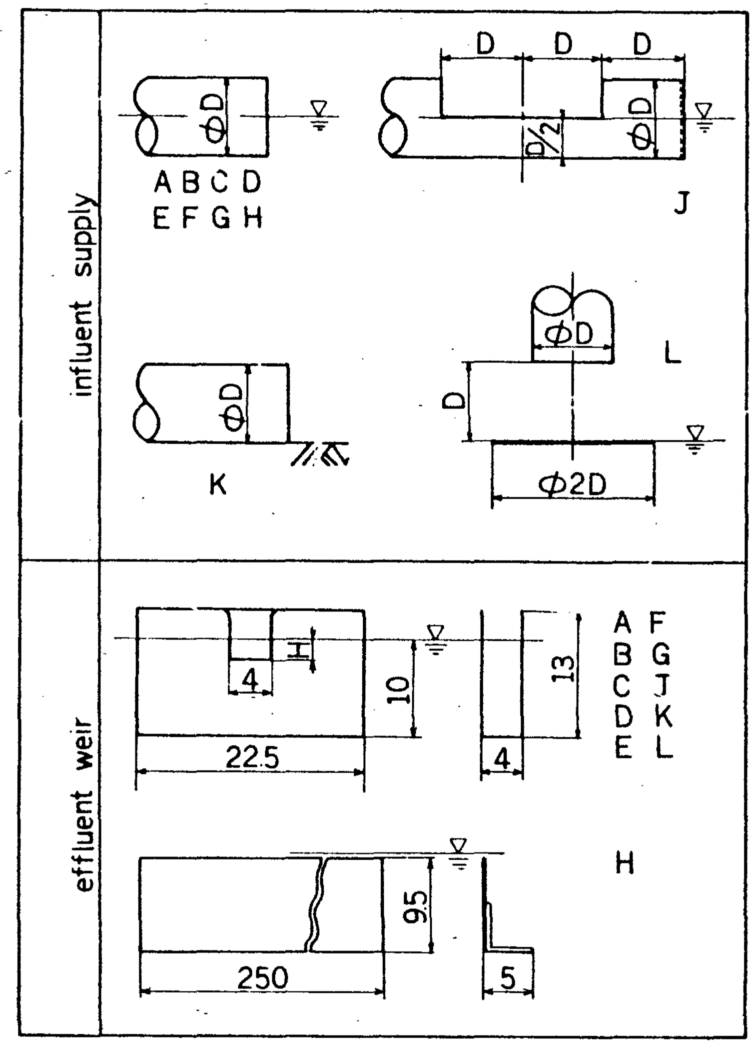

Figure 22. Inlet/outlet structure

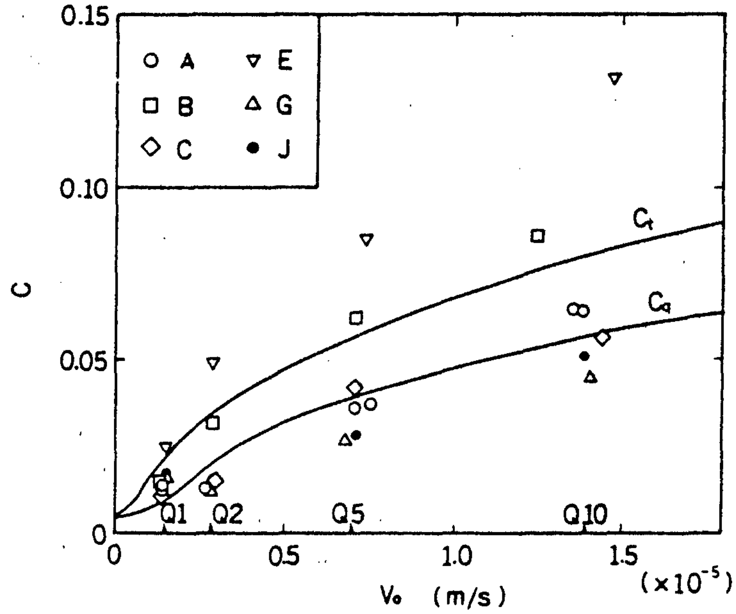

Figure 23. Test results

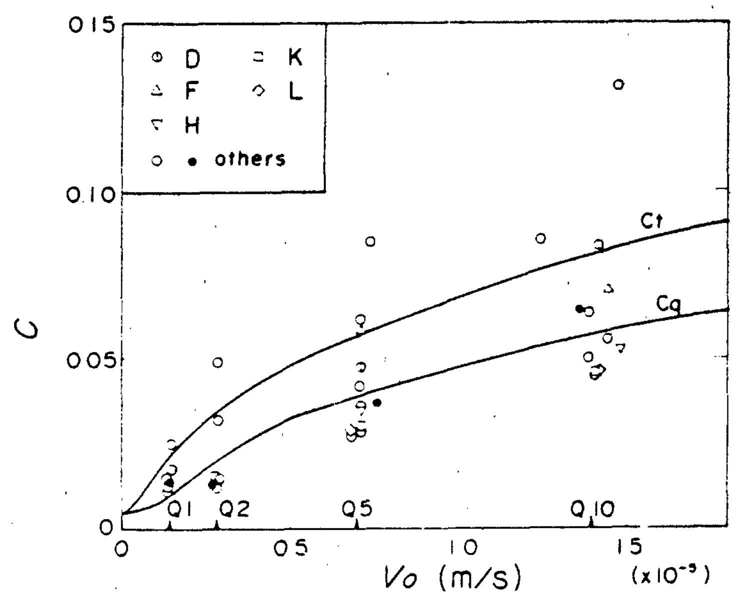

Figure 24. Test results

In type A, the inlet and outlet aligns in longitudinal direction, and the tested value of c is a little higher than c_q at Q10, nearly equal to c_q at Q5 and Q2, and at Q1 c is almost the same as c at Q2. In type B, the inlet and outlet are set parallel but so close that effluent SS concentration is high and near to the value of c_t. Type C also has parallel layout but the distance between inlet and outlet is so long that the effluent SS concentration is generally near to c_q. Type D has a longitudinally aligned layout, but as the sidewall behaves as a training dike because the inlet is close to the wall, effluent SS concentration is higher than that of A. Type E has lateral confrontation layout so SS runoff rate is the highest in all test cases and a significant difference can be recognized between Q1 and Q2 as in the case of type B. Type F is one of the popular layouts, but test results showed it to be less effective than type A. Type G has a longitudinal backward layout of inlet and outlet, which is easy to adopt when a floater inlet pipe is used. This type is classified in the least SS runoff rate group. Type H has a cross-diked weir and is more effective than type A, and its runoff rate is a little less than c_q. Types J and L have modified inlet pipes and almost the same results were obtained for both types. The SS runoff rates were slightly less than c_q, and the difference between rate of influent Q1 and Q2 was little. Type K has an inlet pipe located at the bottom of the containment area. Though some difficulties may appear in practical application, this is one of the most effective types and the runoff rate of this type is less than c_q.

Summarizing the above, types G, J, K, and L can be said to have high SS removal effect; types B, D, E, and F have low SS removal effect; and types A, C, and H exist between the above two groups. Generally, the type in which the velocity around the inlet is low or the flow path is wide has high SS removal effect and the type in which the distance between inlet and outlet is short has low SS removal effect. As the layout of inlet and outlet is often restricted in the field, type C and G are the ideal cases. Type K is not suitable for bottom material containing sand and graval. Type J is simple in structure and is one of the most applicable types in the field.

Comparison Among Installation of Baffle Walls

The removal effect of the settling basin which has baffle walls or a submerged cross dike is compared in this section. Figures 25 and 26 show layout and structure of these types. (1) is a lateral cross submerged dike, (2) is a baffle wall of steel sheetpile, and (3) is a floating curtain with a length half the water depth. Figures 27 and 28 show the test results.

Type b has one submerged cross dike (1). The SS runoff rate of this type was lower than c_q at high overflow rate of Q10 and Q5, and this type was one of the most effective. But at Q1 and Q2, SS runoff rate was close to c_q and a remarkable difference between type A was not observed. Type c has double submerged cross dikes and a little better SS removal effect than type b. Type d has five baffle walls of (2) in a line. The result of this type is near to c_q in the whole range of overflow rate and better than type A at overflow rate Q10. Type e has double lines of baffle walls of the d type. The SS removal effect of it was lower than c_q and better than type d.

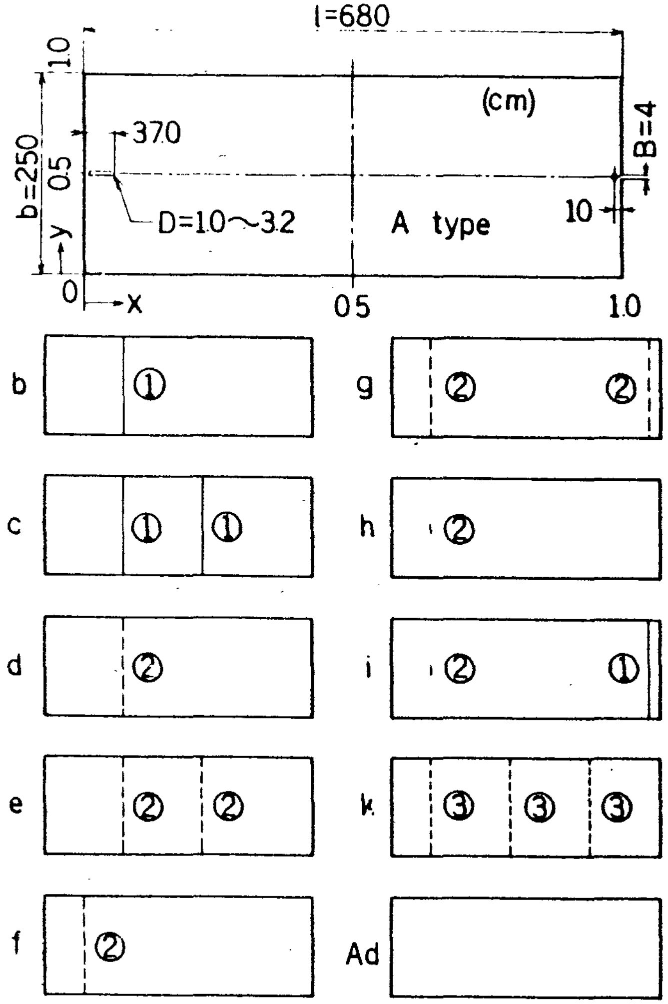

Figure 25. Baffle walls layout types

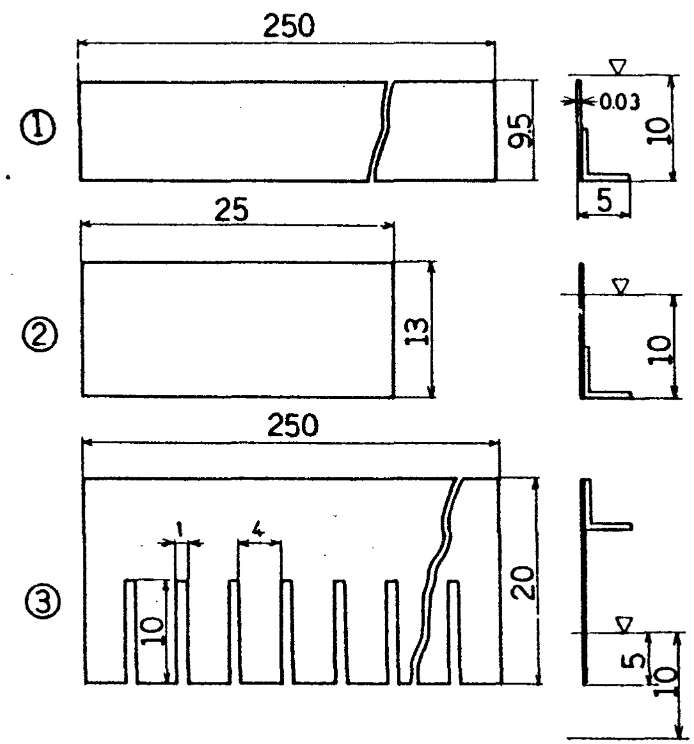

Figure 26. Baffle walls structure

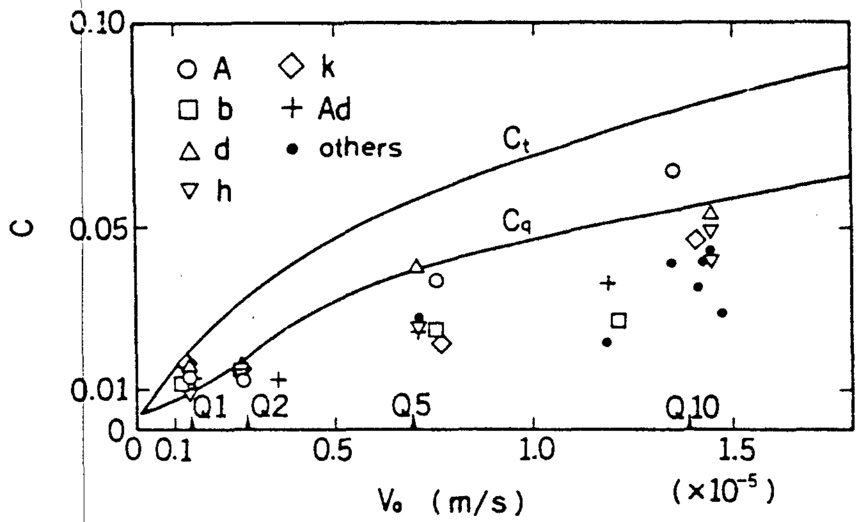

Figure 27. Test results

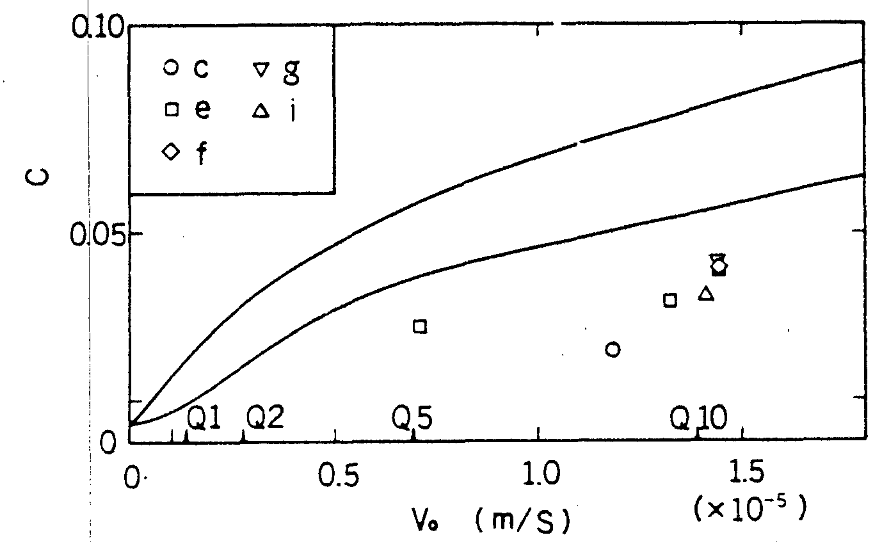

Figure 28. Test results

Type f has baffle walls like type d but the walls' location is close to the inlet pipe. This type was more effective than type d and as effective as type e. Type g has one row of baffle walls at the front of the effluent weir and one row as in type f. When compared with type f, type g does not have a significant difference. Type h has only one baffle wall of 2 in front of the inlet pipe. The SS runoff rate of h at Q10 and Q5 was lower than c_q, and therefore more effective than type A. Type h has higher SS removal ability than type d, which has a row of five baffle walls of 2, and was as effective as types e, f, and g. Type i has an added cross weir of 1 added to type h, and it was a little more effective than type h. Type k has three rows of curtains of 3, and SS runoff rate is lower than c_q at Q10 and Q5 and more effective than type A.

In this series, there were many types which were effective in SS removal. The types which have submerged cross dikes (b and c) are effective especially when overflow rate is large. Among the simple types in structure, type h, f, and k are effective.

In summary, the types where the flow of influent was decreased or the velocity of flow was averaged had a better SS removal effect in large overflow rates. There were several types which are more effective than the types in the former series, but among them there was not much significant difference in removal effect in the low range of overflow rate like Q1 and Q2. On the other hand, it was remarkable that the less effective types of B and E in the preceding series had a clear difference in the removal effect owing to the overflow rate, even for small overflow rates.

CONCLUSIONS

Model tests were conducted on the influence of the SS concentration in the influent on that in the effluent; on the sedimentation promotion effect of inlet/outlet layout types; and on the sedimentation promotion effect of installation of baffle walls in the diked containment area. Tests were carried out using fly ash and Kibushi clay as testing materials. Test data were obtained on ≈20 cases in the first series, ≈30 cases in the second series, and ≈30 cases in the third series. These data were analyzed mainly by comparing them with an ideal settling basin. The following conclusions were obtained.

Influence of Influent SS Concentration

Quiescent Settling Characteristics of Testing Materials

Both testing materials showed line settling in the slurry with more than 10 g/ℓ solids concentration. The SS concentration of the clear water above the boundary increased with the increase of the initial solids concentration in the slurry less than 10 g/ℓ, whereas it decreased with the increase of initial solids concentration more than 10 g/ℓ.

As for the settling velocity distribution, the initial solids concentration of less than 1 g/ℓ did not affect the cumulative settling velocity distribution. For fly ash, settling velocity became higher apparently in

the range of slurry concentration which represents line settling. For Kibushi clay, a similar tendency can be observed, but at 100 g/ℓ slurry concentration, line settling velocity became low.

SS Concentration in Effluent

The SS runoff rate decreased with the increase of influent SS concentration in both testing materials, and an experimental equation, which was a function of void ratio, was obtained. Effluent SS concentration is given by the product of SS runoff rate and influent SS concentration, and becomes maximum at around 10 g/ℓ slurry SS concentration. In the range higher than 10 g/ℓ, the experimental value of effluent SS concentration tends to be higher than the value calculated from the experimental equation, but the value is less than the maximum value of the experimental equation.

Inlet/Outlet Layouts

Types G, J, K, and L have a high SS removal effect; types B, D, E, and F have a low SS removal effect; and types A, C, and H are between the two groups. The type in which the velocity around the inlet pipe is low or the flow path is wide has a high SS removal effect and the type in which the distance between inlet and outlet is short has a low SS removal effect. Though the layout of inlet and outlet is often restricted in the field, type J is simple in structure and is one of the most applicable types in the field.

Installation of Baffle Walls

There are many types which are effective in SS removal. Types b and c, which have submerged dikes, are effective when overflow rate is large. Types h, f, and k are simple in structure and effective. These types are effective in the range of large overflow rate. It can be said that such types where the flow of influent is decreased around the inlet or the velocity of the flow in the containment area is averaged have a high SS removal effect.

COMMENTS

It was verified that, if the distance between inlet and outlet is short, particle removal effect is detrimental, not only in the range of large overflow rate, but also in the range of small overflow rate. On the other hand, the difference of removal effect is large among the types that are effective in the range of large overflow rate; for example, the cross dike is one of the most effective types. But these types do not have significant differences from each other and are not as effective in the small overflow rates. For this reason, it is important to consider the overflow rate in reclamation works, and the decision should be made considering cost performance and reclamation area utilization if solids removal promotion is needed.

From now on, the relationship between settling characteristics in the test column and SS runoff rate, and the influence of the process of reclamation on particle sedimentation, will be investigated and the collection of field data and the study of mathematical simulation will be conducted.

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CAPPING OF DREDGED MATERIAL DISPOSAL MANAGEMENT
FOR NEW YORK HARBOR

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ABSTRACT

The results of monitoring studies conducted on a capped mound of dredged material in the New York Bight are presented. Studies consisted of: a comparison of the physical and chemical characteristics of the sediment dredged from each project, an evaluation of the short- and long-term stability of the cap, and an investigation to quantify contaminant release through the cap using biological monitors. Study results indicate that capping of contaminated sediments is a feasible mitigation measure. In addition, information is presented on a proposed study to investigate the use of depressions in the bottom of the harbor formed by sand mining for the disposal of dredged material with subsequent capping.

INTRODUCTION

Two previous papers (1,2) presented at the Sixth and Seventh Joint U.S./Japan Experts Meeting on the Disposal of Toxic Sediments have explained the background of the sediment contamination problem which was identified in New York Harbor in 1979, and the subsequent capping of this dredged material in the Atlantic Ocean. A series of investigations were initiated to determine the effectiveness of the capping operation. Two major concerns were addressed by the investigations: first, the physical stability of the capped mound and, second, the effectiveness of the cap to seal off the contaminated material from the overlying marine ecosystem. It is the purpose of the first section of this paper to present information on the results of monitoring experiments conducted at the capping site. The second section of this paper concerns

investigation of the use of subaqueous borrow pits for the disposal of dredged material.

CHEMICAL SIGNATURE

The capping experiment at the Mud Dump Site involved the disposal of sediment from ten dredging projects (Table 1) conducted throughout New York Harbor (Figure 1). In order to evaluate chemical and physical differences between each project's sediment and the chemical effectiveness of capping that material, the Chemical Signature Study was initiated. This study was funded by the New York District (Corps of Engineers) and conducted by the Institute of Environmental Medicine of the New York University Medical Center; Dr. Joseph M. O'Connor was project manager.

To obtain representative samples of the sediment from each project, individual samples were taken from barges filled with dredged material from each project. In this way, samples were obtained which represented both the horizontal and vertical variation of the area dredged. Due to the difference in the volume of the material removed from each project, the number of samples obtained for each dredged area varied greatly. For projects with large numbers of samples, up to 15 were selected to represent the entire project.

Sediment cores were taken on two occasions at the Mud Dump Site after capping was completed in November 1980. On 11 December 1980, gravity cores were taken throughout the Mud Dump Site. Coring conducted on 22 August 1981 consisted of vibracores taken in the southeast quadrant of the Mud Dump Site on and adjacent to the capped mound.

Representative sediment samples from the barges and the cores were analyzed for their physical properties, including: water content; grain size; organic carbon and radionuclides; metals including cadmium, copper, lead, zinc, and mercury; chemical oxygen demand; and organics including PCB, pesticides, PAH, and aliphatics (3).

Interproject comparison of the barge samples revealed that the sediment from Ambrose Channel was unique in that all other projects had less sand, more silt and clay, more water, and more organic matter. Intercomparison of the other projects revealed that, for individual parameters, groupings of projects could be made that had similar values. Only one project, Jackson Engineering, could be identified as "unique" due to its extremely high levels of copper, zinc, and lead. Generally, intraproject variation was great enough to obscure chemical or physical differences between projects.

Chemical and physical analysis of the core samples indicated distinct sediment layers in some cases. At the capping site, sand was found in varying thicknesses in the top layer. X-radiographic data of the cores taken in August 1981 indicated that the sediments possessed a surface layer of sand ranging from 0.24 to 1.58 meters in thickness (Bokuniewicz, unpublished data). The average thickness of the sand layer was 1.08 meters.

Inclusion of the dredged material from the Bronx River and Westchester Creek as part of the cap complicated the discrimination of that material.

Table 1. Dredging projects and sample numbers available for analysis of chemical signatures.

Project No.	Waterway	Facility[a]	Location	No. Samples Available	No Samples Run
1	Hudson River	U.S. Gypsum	Stony Pt., N.Y.	54	11
2	Hudson River	Port Authority Term.	Manhattan	76	14
3	Hudson River	Sea Train Terminal	Weekhawken, N.J.	22	10
4	Newark Bay	Port of Newark	Newark, N.J.	29	15
5	Kill Van Kull	Jackson Engineering	Staten Island, N.Y.	41	11
6	Passaic River	Monsanto Corporation		2	2
7	Hudson River	Westchester Cty STP	Yonkers, N.Y.	2	2
8	Bronx River	Hunt's Pt. Terminal	Bronx, N.Y.	73[b]	10
9	Westchester Creek	--	Bronx, N.Y.	41[b]	10
10	Ambrose Channel	--	--	250[b]	5

[a]If no facility specified, project was general approach channel.
[b]Number of samples represents estimate.

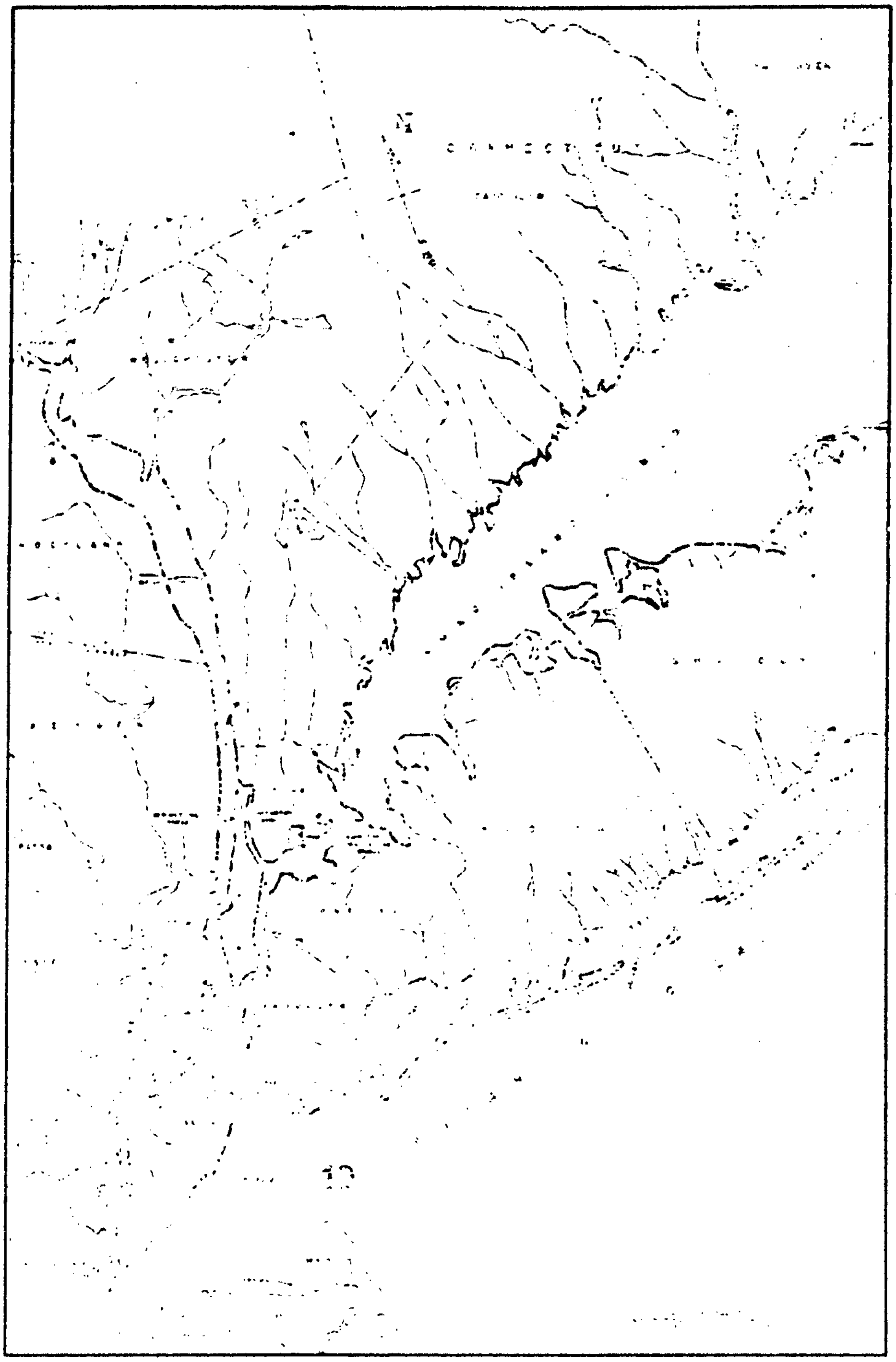

Figure 1. Location of dredging projects involved in capping experiment

Although bioassay and bioaccumulation testing (1) indicated that these two projects were not toxic and showed no unacceptable bioaccumulation potential, chemical analysis of the sediment indicated that, for the parameters evaluated, no significant difference existed when compared to the dredged material which was capped.

The biggest problem encountered in evaluating samples from the material capped was that in addition to there being a great deal of intraproject variation, many of the projects were disposed at the same location concurrently. This reduced the possibility of detecting distinct sediment layers for each project. However, chemical analysis of a portion of a core obtained in December 1980 did reveal an area which exhibited the chemistry of the material dredged from Jackson Engineering.

O'Connor (3) concluded that, for dredged material contaminated with metals, PCB, PAH, and/or other organic contaminants, the placement of a sand cap is a reasonable mitigation measure. A permanent sand barrier would increase the distance between the overlaying seawater and the contaminated fine-grained sediment and reduce the potential for resuspension of this material.

SEDIMENT TRANSPORT

One of the assumptions made prior to conducting the capping experiment at the Mud Dump was that the sand cap would remain in place. Previous research has been conducted with a mound of dredged material in the northwest corner of the Mud Dump to ascertain the quantity of sediment movement from the site. Freeland and Merrill (4) and Freeland et al. (5) examined dredged material disposal volumes for the period 1936 to 1973. They determined that 87% of the volume disposed was accounted for at the Mud Dump. Utilizing the same data, Dayal et al. (6) calculated the dry mass of material disposed, assuming an average dry density. They determined that, on a dry mass basis, 82% of the dredged material could be accounted for. However, using disposal records for the period 1973 to 1978 for which the data are more accurate, the dry mass of material disposed which can be accounted for approaches 98%.

To verify this observation for the capped mound, the Atlantic Oceanographic and Meterological Laboratories of the National Oceanic and Atmospheric Administration (AOML/NOAA) with funding support from the New York District conducted the Sediment Transport Study. This study was undertaken to determine: (a) changes to the cap as a result of bottom currents and sediment transport over the winter of 1980-1981; (b) the bottom current velocities necessary to initiate erosion of the cap; and (c) the long-term probability of erosion by wind-generated waves.

Two cruises were conducted, November 1980 and June 1981, to collect field data at the Mud Dump. Sidescan sonar (sonographs) of the bottom microtopography and surficial sediment samples were obtained. In addition, the New York District conducted bathymetric surveys of the capping area upon completion of capping, and six months and one year postcapping.

Analysis of these data by AOML/NOAA (7) indicated that the cap showed

only a slight decrease in grain size. Microtopography data indicated that sediment transport had resulted in smoothing out the bottom roughness which will tend to inhibit further erosion. It is likely that some of the sand cap was eroded and replaced by fine-grained sediment from elsewhere in the Mud Dump. This intermixing of grain sizes results in poorer sorting and a reduction of mean size which tends to extend cap life. The slight amount of erosion indicated by comparison of bathymetric surveys was less than the margin of survey error. Inherent in this comparison calculation is the determination of accurate figures for quantity of dredged material in-place at the disposal site upon completion of capping. Tavolaro (8), using a dry mass balance approach, determined a sediment budget in order to identify and quantify "losses" of dredged material from the time it is dredged to the time it is in place at the disposal site. Tavolaro concluded that approximately 2.0% of the dry mass measured in-place at the dredging site is unaccounted for in the barges and was assumed to have been "lost" during dredging. Approximately 3.7% of the dry mass measured in the barges was unaccounted for at the Mud Dump and was assumed to have been "lost" during disposal.

Field experiments to determine the threshold current velocity needed to initiate resuspension of the cap were accomplished utilizing a seagoing flume (Seaflume). The Seaflume photographically recorded bottom sediment response to a systematic increase in flow velocity generated by a self-contained submersible pump and motor assembly. The Seaflume was deployed in 12 locations on the capping area. Freeland et al. (7) found that threshold shear velocities at the seabed interface ranged between 0.6 to 1.4 cm/sec, with erosional current velocities 100 cm above the seabed from 14 to 31 cm/sec. To determine the frequency of events which would generate sufficient shear velocity to erode the cap, two investigations were conducted. During the November 1980 cruise two concentration-velocity (CV) probes were deployed on the capping area to measure currents and suspended sediment concentrations. The CV probes remained on the bottom, recording data until June 1981. The CV probes consisted of microprocessor controlled electromagnetic current meters coupled with an optical transmissometer for turbidity measurements, mounted together on a tripod (7). Calculations of suspended matter concentrations were complicated by continued dredged material disposal 1.5 kilometers to the north and sewage sludge disposal 10 kilometers to the east. Freeland et al. (7) found that the mean currents 100 cm above the bottom were generally on the order of 6 to 7 cm/sec, with a net direction to the south.

Freeland et al. (7) used wave hindcasting involving the wave spectral model and the wave parametric model to calculate the hydraulic climate at the Mud Dump. The first model was based on the integration of the wave energy balance equation while the second assumed an approximate invariance (9) of the normalized wave spectral shape with fetch.

Freeland et al. (7) extrapolated existing wind and wave data from the area around the New York Bight Apex to the Mud Dump. By comparing these data with that obtained from the CV probes, they determined that the measure of wave energy shows a strong correlation with turbidity. However, the wave period does not correlate with the wave energy or bottom current velocity. The depth of the capping site dampens the energy of surface waves and only the larger waves propagate to the bottom. In conclusion, Freeland et al. (7)

determined that wave hindcasting adequately outlines the impact of surface wave climate on bottom sediments but it also shows that not all bottom wave energy is generated locally. Freeland et al. (7) suggested that under long-term averaged waves and currents, little change in cap thickness would occur after 100 moderately energetic transport events. Swell waves generated by hurricanes are capable of producing wave heights reaching 13.5 meters (7). However, storms of this magnitude are not numerous enough to warrant probability analyses.

BIOACCUMULATION MONITORING

A basic premise of the capping of contaminated dredged material is that, to be effective, the cap must seal off the contamination present from the surrounding environment. To determine the success of the cap placed in the Mud Dump, it was decided to utilize a biological monitor to quantify contaminant release. The blue mussel, *Mytilus edulis*, is recognized as a suitable organism for monitoring coastal pollution in the International Mussel Watch (10) and has been previously used by the New England Division of the Corps of Engineers to monitor contaminant release from a capping experiment in Long Island Sound (11). Under contract to the New York District, investigators representing the New Jersey Marine Sciences Consortium conducted a one year biomonitoring study of adult blue mussels transplanted to selected stations within the New York Bight Apex. Reference stations were selected to quantify contaminant impacts to the capping area originating from outside sources such as the Hudson River and sewage sludge disposal. Control stations were established outside known sources of pollution, first along the southern coast of Long Island and later along the east coast of New Jersey. To determine the biological impact of disposed dredged material, one station was placed on an uncapped mound of dredged material in the Mud Dump Site formed since 1914. Another station was established on the capping site upon completion of disposal of the cap.

The mussels were deployed in twelve mesh bags (100 per bag) suspended 1 meter above the bottom from platforms (Figure 2). Initial deployment was made in August 1980. Premature loss of mussel platforms occurred at three of the six August deployment stations. The destroyed control station was relocated and a new platform was deployed at the same time the station was established on the capping site, January 1981. One bag of mussels from each platform was collected weekly for the first month and thereafter bimonthly. Mussels were checked for survival rate and bioaccumulation of mercury, cadmium, lead, PCB, DDT, and petroleum hydrocarbons (as represented by No. 2 fuel oil) (12). Mortality data for the experiment were invalidated due to an unexplained survival of only 54% of the mussels after one week at the control site. A bag retrieved later at the same control site did, however, have a survival rate of 90%.

Prior to the deployment of the platforms, tissue analyses were conducted on a representative subsample of the mussel stock to ensure that the mussels were not contaminated. A slight elevation of lead (0.83 ppm) was the only contamination noted.

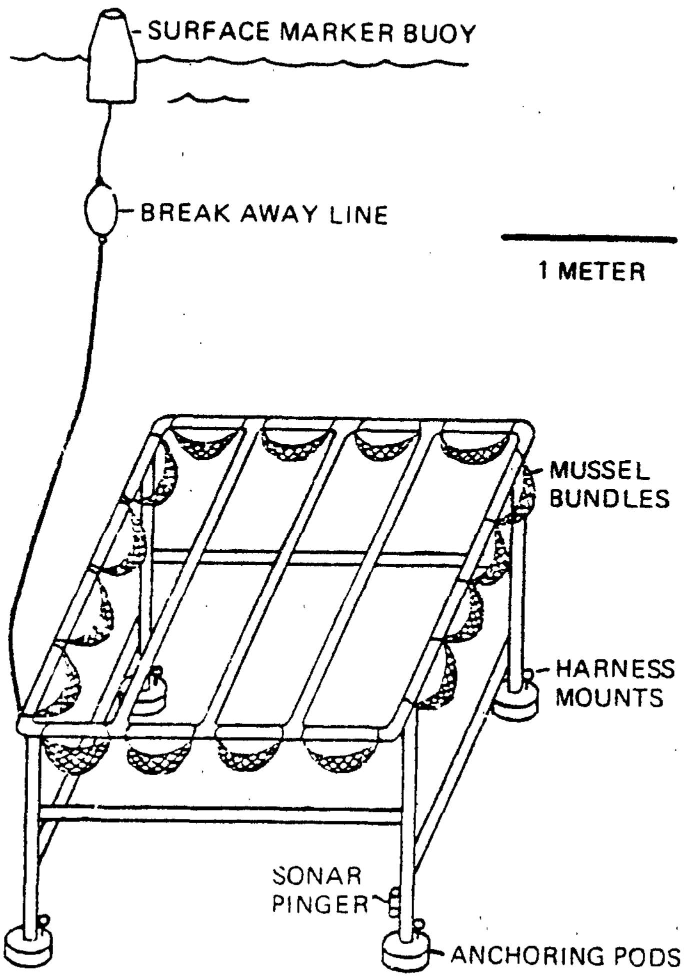

Figure 2. Mussel incubation platform

Bioaccumulation of metals was very erratic for the first 5 to 7 weeks. By the tenth week, differences between stations could be noted and generally the plateau level had been reached. Regression analysis of the data indicated that, in all cases, the highest value was found at the uncapped mound of sediment existing in the northwest corner of the Mud Dump (Mean values in ppm; Hg 0.242, Cd 0.081, and Pb 1.13). The next highest mean values were found at reference stations 1 to 2 kilometers from the Mud Dump. Mean bioaccumulation values for metals at the capping site were quite low for mercury and cadmium (0.030 and 0.041, respectively) while lead was not statistically different than the uncapped mound value at 1.04 ppm.

PCB bioaccumulation showed wide fluctuations throughout the study. No conclusions could be drawn from the results as to the source of PCB or the reason for the fluctuations in values. PCB bioaccumulation in this study could not be correlated with mussel lipids, in deference to the propensity of data indicating a positive correlation.

Bioaccumulation values for DDT were generally below detection for mussels from all stations. This finding corresponds to the lack of statistically significant bioaccumulation of DDT for any sediment proposed for ocean disposal within the New York Harbor Area.

Results of No. 2 fuel bioaccumulation over time indicated that after a minimal accumulation in the first four weeks of exposure, no further change was detected until there was a dramatic increase in late spring. The pattern of mean values of No. 2 fuel oil concentration was generally the inverse of the pattern shown for metals concentration. Mean fuel oil concentration at the capping site (0.667 ppm) was greater than that for the uncapped mound (0.20 ppm) and all other reference stations.

Koepp et al. (12) concluded from this study that: (a) mussel survival and lipid content did not statistically correlate with bioaccumulation of any contaminant for any given station; and (b) the absence of ancillary contaminant data for sediment, water, and mussel food restricted the extent to which the observed contaminant accumulations can be more specifically related to dredged material disposal.

SUBAQUEOUS BORROW PITS

Subaqueous borrow pits are irregularly shaped depressions on the sea floor caused by sand and gravel mining, typically for construction material and beach replenishment. In an area within 160 kilometers of New York City, the demand for this material has been predicted to be about 10 million cubic meters per year (13). Most sand mining in the New York Harbor area is confined to the Lower Bay which is composed primarily of sand and gravel (14).

The volume of existing borrow pits in the Lower Bay is about 23 million cubic meters (15). The idea of using borrow pits as containment sites for dredged material is not new. It was suggested as early as 1973 by Carpenter (16). Technology is available to carry out a disposal operation over a borrow pit. Volume I of the Mitre Report (17) identified the use of subaqueous borrow pits as feasible for large volumes of dredged material and a possible option for disposal of contaminated dredged material.

The filling of borrow pits is an environmentally beneficial dredged material disposal option since borrow pits are known to be subject to a high rate of fine-grained organic sediment deposition, with attendant adverse environmental impacts (18, 19, 20). When disposal of fine-grained dredged material is combined with the placement of a layer of sand as a cap, the area can be restored to its original condition and productivity of the area should increase. The filling of borrow pits with fine-grained dredged material does have the unavoidable consequence of removing that immediate area from any future sand mining operation.

In order to evaluate subaqueous borrow pits as a dredged material disposal option, the New York District initiated a contract with the Marine Science Research Center at the State University of New York at Stony Brook (MSRC). MSRC had previously spent several years investigating the environmental effects of sand mining and filling of the borrow pits within the Lower Bay. Model studies were conducted and the results evaluated. It was determined that a demonstration project was required to obtain further information on the feasibility of combining the two operations.

Site selection consisted of an evaluation of the following factors:

1. Site must be accessible to barges for the disposal operation.

2. Site must be such that the pit is deep and large enough to contain the spread of the dredged material when it encounters the bottom.

3. Site must be outside areas susceptible to high wave and current energies.

4. Site must not be an area of high biological productivity.

5. Site must not be an area of current sand mining operation.

Evaluation of the above criteria revealed that no currently existing borrow pit was totally acceptable. Investigation was made of the idea of creating a borrow pit of ideal dimensions in an ideal location. This idea was dismissed because of the high cost and the disruption of an undisturbed area. It was determined that the best option available was to modify an existing borrow pit.

A borrow pit located in the center of the Lower Bay was chosen as the site for the Demonstration Project (Figure 3). The purpose of the Demonstration Project was to assess the physical stability and technical feasibility of capping dredged material within a subaqueous borrow pit. This borrow pit was originally dredged in the early 1970's to a depth of 28 meters below mean low water. Since that time, approximately 3.8 million cubic meters of dredged material has been disposed there, in an effort to alleviate the anoxic condition present in the bottom of the pit. Schwartz and Brinkhuis (21) have documented that a high rate of natural sediment deposition, low dissolved oxygen, and impoverished benthic fauna exist at this borrow pit. The sedimentation rate in the pit (on the order of 10 centimeters/year) was reported to be 100 times that of natural sedimentation rates in other estuaries, while no

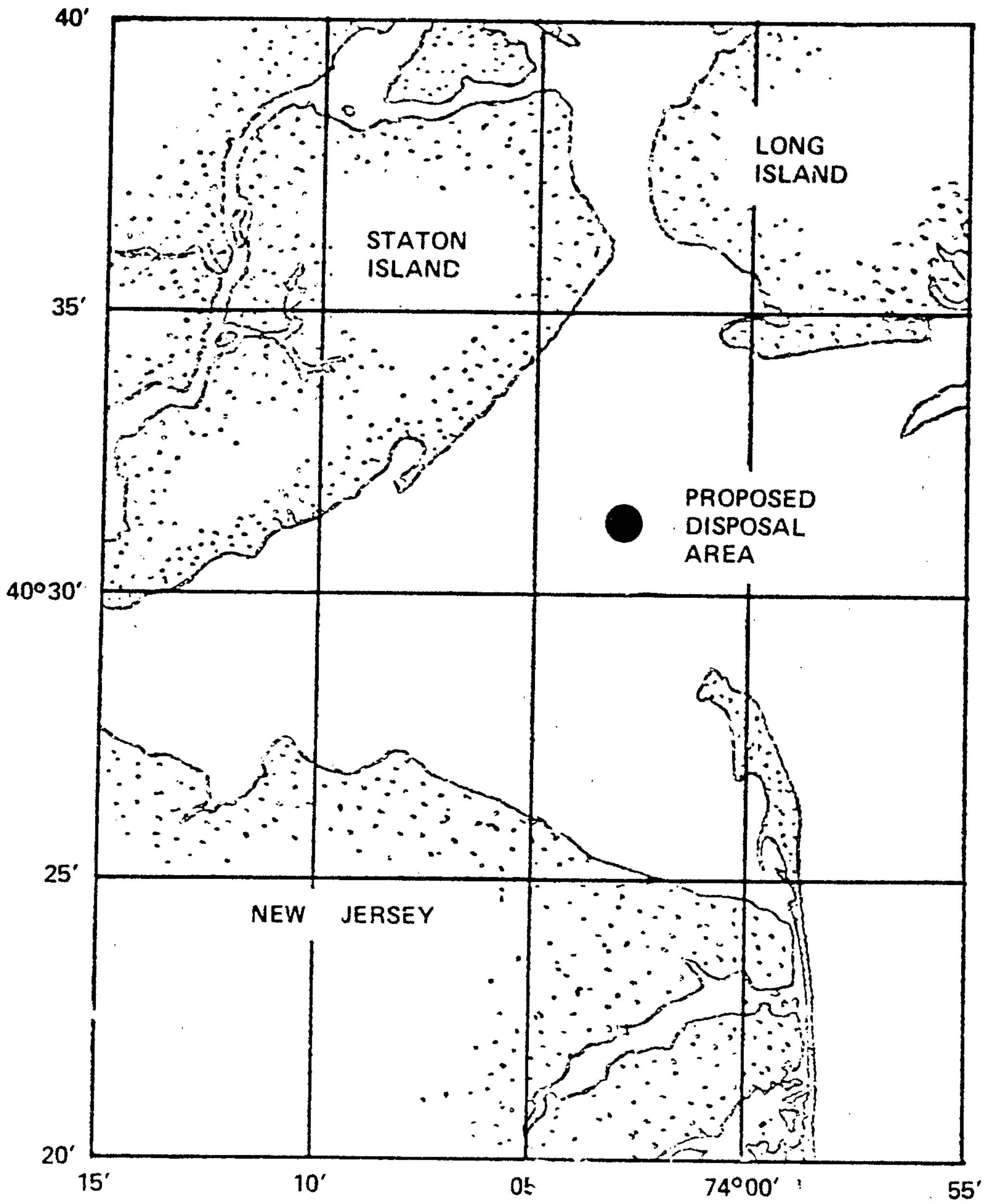

Figure 3. Site location of bor· w pit to be used for Demonstration Project

sediment was found to be accumulating on the shallower sandy bottom surrounding the pit. Due to the organic fraction of the sediment which exerts a high biological oxygen demand and has certain contaminants chemically bound to it, the borrow pit supports a benthic community of about 137 organisms per square meter while the surrounding area supports about 1100 organisms per square meter (15).

Because the remaining capacity of the borrow pit, 3.8 million cubic meters, was determined to be too large, it was decided to conduct the project in three phases. As proposed, phase I (Figure 4) of the Demonstration Project would involve the disposal of approximately 153,000 cubic meters of sand. The disposal of this material would accomplish two objectives. First, it would be used to determine the energy of the surge of the dredged material once it hits the pit bottom. Second, the material would be disposed so that it would form a three-meter-high berm across the southern portion of the borrow pit to create an isolated pocket consisting of 10 to 15 percent of the volume of the entire pit.

Phase II of the project would consist of the disposal of approximately 300,000 cubic meters of fine-grained sediment. This material would be nontoxic and uncontaminated sediment as demonstrated by bioassay and bioaccumulation testing. The phase II sediment would be placed behind the berm.

Phase III would involve the disposal of 230,000 cubic meters to cap the phase II material. This dredged sediment would be non-toxic and have no unacceptable bioaccumulation potential, and at least the top 0.3 meters would consist of clean sand the same grain size as the surrounding bottom. Upon completion of phase III, a monitoring program would be initiated to determine physical and chemical changes to the borrow pit and surrounding area.

During the month of December 1981, 167,000 cubic meters of sand was dredged from the Federal Navigation Project at Ambrose Channel for construction of the berm. Disposal was accomplished utilizing the Corps of Engineers hopper dredge Goethals. This created an isolated area with the dimensions 200 meters wide by 200 meters long with a maximum depth of 14 meters below mean low water.

Prior to the initiation of phase II, the Water Quality Certification issued by the New York State Department of Environmental Conservation authorizing the project was challenged in state court by a private environmental organization. It was the allegation of the environmental organization that the borrow pit proposed for the Demonstration Project was an area of high biological productivity and, as such, an Environmental Impact Statement should have been prepared. At this time, the lawsuit has not been resolved. In the interim, the New York District Corps of Engineers has been funding two studies to further evaluate the biological productivity of the borrow pit and determine its relative importance compared to the rest of the harbor. Analysis of the results of these two studies is anticipated to be completed by the end of 1982.

CONCLUSIONS

In 1980, the New York District conducted a capping experiment to resolve an urgent need by several permit applicants to dredge sediment which exhibited

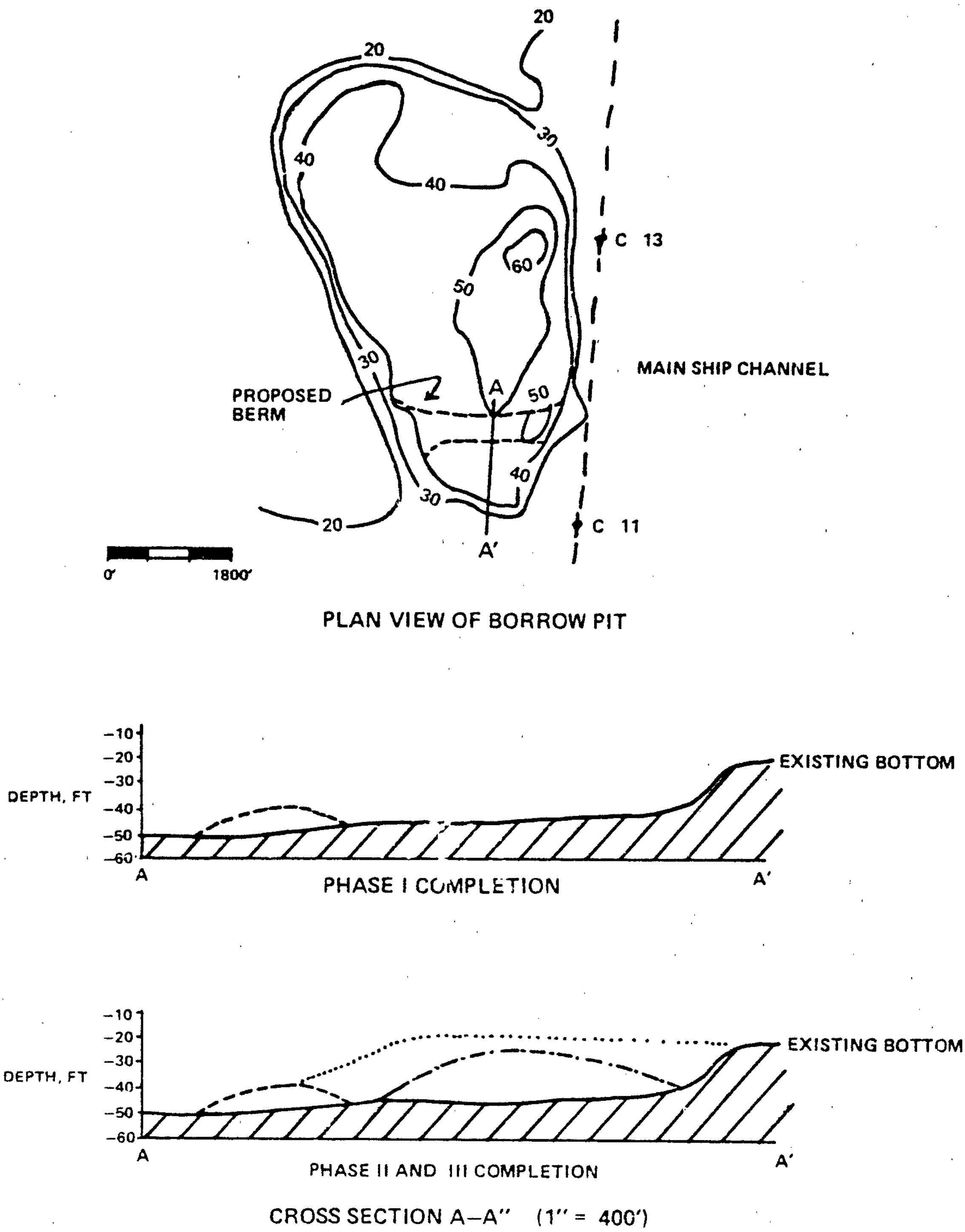

Figure 4. Proposed borrow pit Demonstration Project

a statistically significant bioaccumulation of PCB. The capping exercise was based upon two premises: (1) that the capped mound would be physically stable, and (2) that the cap would seal off the contaminated material from the marine environment. Results of studies presented in this paper indicate that these premises have been fulfilled.

Currently the New York District is utilizing capping to allow some contaminated dredged material, for which no other disposal option exists, to be capped in the ocean. In addition, as part of a dredged material disposal management program, all ocean disposed dredged material is dumped at a taut-moored buoy in the Mud Dump Site. In this way, sediment in need of capping receives a covering of additional uncontaminated dredged material to further isolate the contaminated material.

The ultimate solution to the problem of dredged material disposal is to have a sound management strategy which can clearly predict the most environmentally sound and economically feasible disposal option. A successful investigation of the subaqueous borrow pits would increase the options available for contaminated dredged material containment. With a variety of disposal options available, dredging projects can be planned and carried out in a timely fashion thereby maintaining economic integrity of the Port of New York and New Jersey while at the same time protecting environmental resources.

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RESTORATION STUDY OF DREDGING
IN LAKE KASUMIGAURA

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INTRODUCTION

Lake Kasumigaura is the second largest lake in Japan and is eutrophic. The sediment has adverse effects upon water quality and has a thickness of about 40 - 50 cm.

In order to remove sediment as a link in the chain of restoration, dredging is now partly under way. However, problems remain as to how the secondary impacts by dredging can be abated and how to manage the dredged material. An outline of past and future studies of these problems is presented herein.

BACKGROUND

Lake Kasumigaura (Figure 1) is situated in the southeast of Ibaragi Prefecture, which is located nearly in the center of the east coast of the Nippon Islands. It connects to the lower part of the Tone River through Hitachi Tone River and has the second largest area in our country with 56 inflowing rivers.

Basin data are presented below:

Basin area	2169 km^2
Towns and villages	47 (23 environs of the lake)
Average annual rainfall depth	1350 mm
Average annual rainfall quantities	$2.82 \times 10^9 m^3$
Average annual runoff discharge	$1.39 \times 10^9 m^3$
Average annual runoff rates	49%
Population	720,000

As the above data show, the basin area of Kasumigaura is 2169 km^2 and occupies about 35% of the total area of Ibaragi Prefecture.

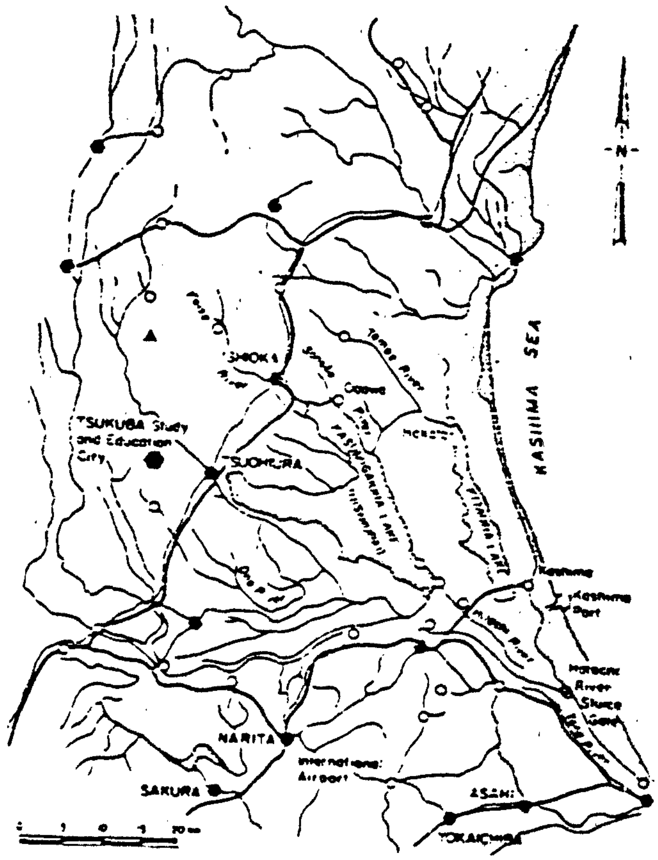


Figure 1. Kasumigaura Basin

The average annual rainfall depth is about 1350 mm and the total quantity of inflowing water is $1.4 \times 10^9 m^3$ and lake water volume is replaced 1.7 times/year.

Most parts of basin have a stretch of hills with a height of 20 - 30 m, or flat land (like rice fields) around the lake, except for several mountains like Tukuba (876 m) and Kanami (709 m).

There are 56 inflowing rivers such as Onogawa, Sakuragawa, Koisegawa, Sonobegawa, and Tomoegawa and only one outflowing river, Hitachi Tone.

Hitachi Tone River has a small bed inclination and complicated hydrologic conditions because of the brackishness of the water and the influence of the water level in the Tone River.

The basin has 47 towns and villages extending over the two Prefectures of Ibaragi and Chiba and a population of 720,000. Industries in the basin are mainly primary industries. Among them, two are prominent: hog raising and carp farming.

The morphometry of the lake is as follows:

Water level	Y.P.* + 1.0 m average sea level + 0.16 m
Lake area	220 km^2
Coastal line	252 km
Max depth	7 m
Mean depth	4 m

To meet an increasing water demand in the capital city and its environs, an integrated Kasumigaura development project (Figure 2) is now moving

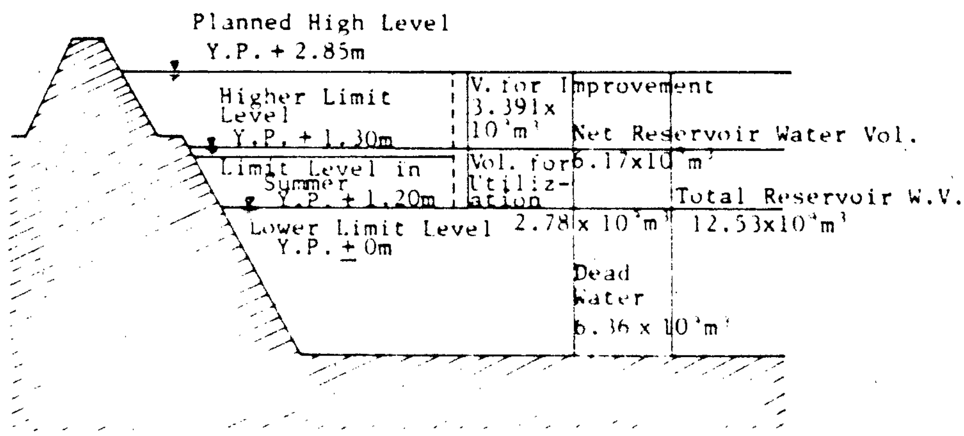


Figure 2. Volume allotment in Kasumigaura

* Y.P. = datum plane elevation of Tone River works.

forward in terms of water improvement and utilization. It aims to develop water quantities of $280 \times 10^6 m^3$, which correspond to the volume between Y.P. + 1.3 m and Y.P. $\pm$ 0 m by the project completion year of 1985.

Furthermore, big projects developing the Kashima seaside industrial area and the Tsukuba research and education zone are promoted along with this water resources development.

The lake water is now maintained as fresh water by use of a backward flow protecting floodgate, which was built in 1963 for river improvement at the lower part of the Hitachi Tone River. In this way, Kasumigaura has become a large artificial water reservoir. Therefore, close attention must be paid to protect its water quality.

OUTLINE OF WATER AND SEDIMENT QUALITIES

The water quality in Kasumigaura has deteriorated in such a way that chemical oxygen demand (COD) concentrations, which were about 4 ppm in 1955, have increased to 7 - 8 ppm in the latter half of 1965 and to 10 ppm after 1978.

The environmental standard for COD for Kasumigaura was designated in 1972 as 3 ppm considering the water purposes. But as Figure 3 shows, water quality has become remarkably worse since 1970 and, at the present state, greatly exceeds the guideline.

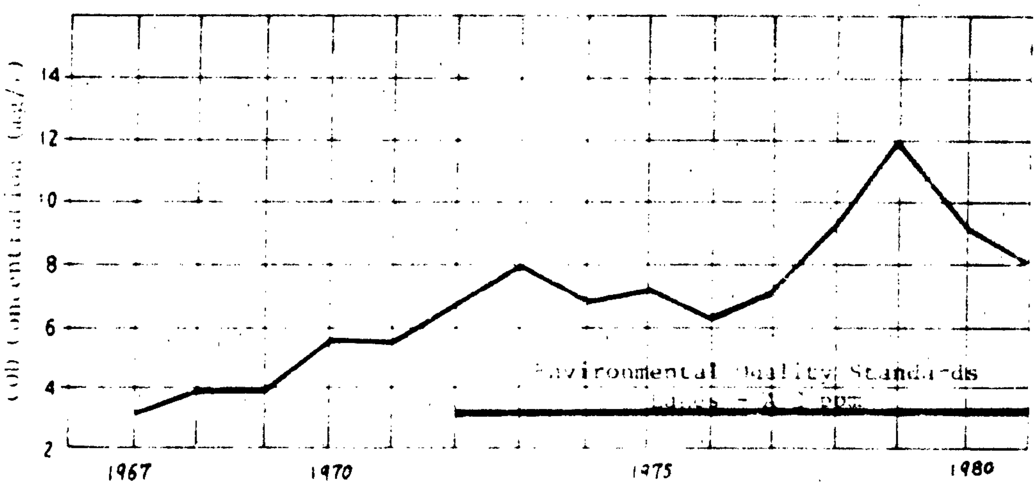


Figure 3. Change in COD concentrations

As countermeasures for this water deterioration, the regulation of effluents was strengthened and sewage systems were consolidated. However, even with these measures, the present state of water quality still tends to become worse.

In summer a eutrophication phenomenon occurs in that phytoplanktons fed by nitrogen and phosphate breed in high water temperatures. As the water flow

velocity is low in stagnated water areas such as lakes, most suspended solids settle to the lake bottom and result in pollution of the sediment.

Polluted sediment adversely impacts upon water quality through the nutrient materials that are released from sediment and eluded from the resuspended solids. This is an internal lake pollution load.

In eutrophic lakes like Kasumigaura, phytoplankton are produced by nutrient inputs. Dead matter settles to the lake bottom where it decomposes, and nutrients are released from sediment, spread up the water body, and help regenerate plankton.

Since release phenomena are vigorous in high water temperatures, the lake experiences blue-green algae blooms in summer. In this way, sediment in Kasumigaura is degraded similar to water. It spreads in the whole lake accumulating from several centimeters to scores of centimeters in thickness.

WATER QUALITY IMPROVEMENT PROJECT IN KASUMIGAURA

Domestic drainage, factory effluents, and rural drainage are considered as pollution sources. The internal load by released material from sediment is also presumed to be a cause of pollution.

To meet these problems, dredging commenced in 1975 as a restoration measure (supervised by direct national administration for implementing river environmental improvements).

The quantities of sediment to be removed in Kasumigaura reservoir area project have been set at 300,000 m^3 by 1981. Dredging is now continuing at heavily polluted offshore estuarine areas such as Sakuragawa (Tsuchiura City) and Koisegawa. Table 1 shows the dredging results.

Table 1

Dredged Volume

Year	Dredged Volume, m^3	Accumulated Volume, m^3
1975	4,000	4,000
1976	18,000	22,000
1977	13,000	35,000
1978	34,000	69,000
1979	40,000	109,000
1980	85,000	194,000
1981	106,000	300,000

In Kasumigaura the dredge KASUMI (with negative pressure suction) was developed to prevent secondary impacts from turbidity. An improved dredge KŌRYU was put into operation in 1978. Most of the dredged material is dewatered at management ponds by normal densification methods or by progressive trenching and then used for banking embankments in city public spaces.

In addition to the dredges, a special boat for gathering phytoplankton was developed and operates during the summer.

The local government (Ibaragi Pref.) issued "the regulations to prevent eutrophication in Kasumigaura" and enacted the following countermeasures beginning in September 1982:

(1) Consolidation of sewage systems for domestic drainage and prohibition of the sale of cleaning agents containing phosphorus.

(2) Strict observation of effluent regulation standards and strengthened regulation of effluents.

(3) Guidance for correct fertilization to control rural drainage.

(4) Consolidation of domestic animal excreta control facilities for stock effluents.

(5) Rationalization of carp farming method and change in fish species.

(6) Dredging of inflowing rivers and control of aquatic plants.

VACUUM SUCTION AND PNEUMATIC DISCHARGE DREDGING SYSTEM

A dredge with a vacuum suction and pneumatic discharge system was built in 1978. It has the following features:

(1) Minimal turbidity can be expected.

(2) A swing method is maintained for dredging to increase operational efficiency.

(3) A liquid pressure pump (max pressure 40 kg/cm^2) is maintained for discharging dredged material.

(4) It is equipped with devices for inspecting the excavation and measuring the sediment volume.

The main data of the dredge are as follows:

Max dredging depth	7 m
Conveying distance	2000 m
Dredging capacity	Over 100 m^3/hr (water content of 2000%)
Diameter of delivery pipe	150 mm
Capacity of suction pump	2 × 0.85 m^3
Vacuum pump	720 m^3/hr, -500 mm Hg
Screw type air compressor	1 × 1200 m^3/hr, 7 kg/cm^2

Working Principle of Vacuum
Suction and Pneumatic Discharge Pump

The suction head, which consists of two sediment hoppers and a suction mouth, exhibits suction and discharge actions alternatively by valves such as suction switch valves, suction valves, and ball valves (Figure 4).

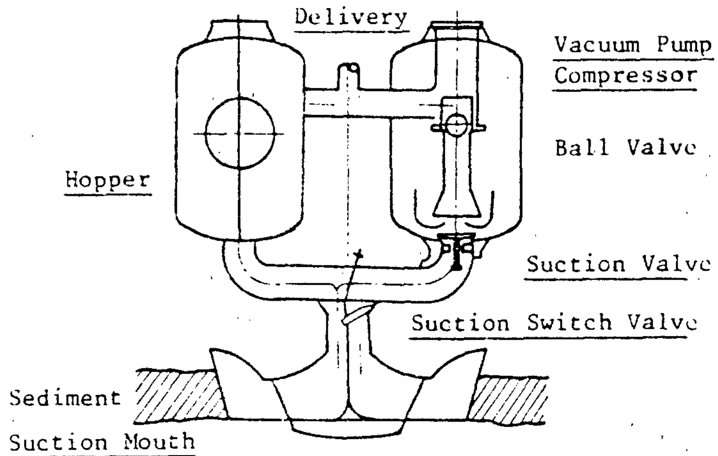


Figure 4. Working principle of pump

The vacuum pump acts at a vacuum of -500 mm Hg; when the required quantities of dredged material are filled into one hopper, the suction process is stopped by the working of the level switches. Then compressed air (7 kg/cm^2) is automatically supplied to the hopper by the air switch-over valves to push out the sediment with the help of the ball valves. When the remainder reaches the lower limit level, exhausting of sediment is stopped by the working of the level switches. By repeating these processes through alternative use of the two hoppers, continuous and smooth dredging is achieved (Figure 5).

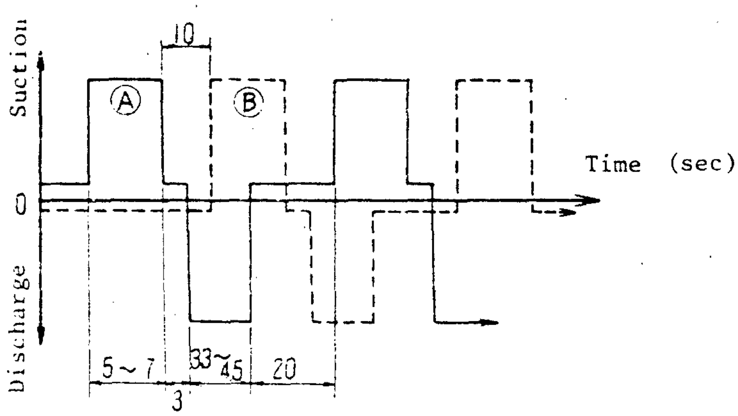


Figure 5. Diagram of dredging action using alternate hoppers

The Digger and Its Performance

As Figure 6 shows, the digger has an open suction mouth, which is shaped so as to be able to suck sediment continuously by using a swing system.

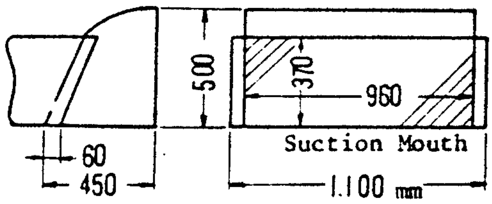


Figure 6. Shape of digger

It is known that the shape of the suction mouth has a large effect upon dredging performance regarding sediment disturbances from dredge impact.

When removing upper sediment layers, it is necessary to minimize the intake of water in the sediment surface for efficient removal. This requires not only a good shape of the suction mouth, but also consideration of various sediment properties and dredging conditions such as dredging depth and swing speed. Tests on two kinds of suction mouth shapes were performed concerning this problem.

The relationship between digging height and water content is shown in Figure 7, using zero height for the contact face of the digger bottom and sediment.

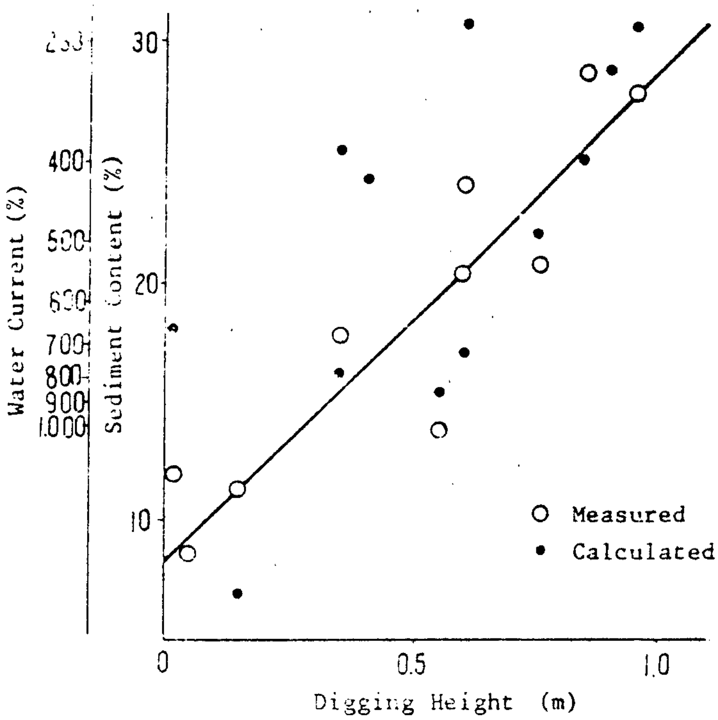


Figure 7. Relationship between digging heights and water content

At that time swing speed was left to the judgment of the operator to maintain smooth dredging. These tests emphasized sediment content over removal efficiency and the finishing accuracy of the dredged surfaces.

From these data it can be said that:

(1) The sediment content of the surface of the dredged material is about 14%. This value slightly exceeds 10 - 13% normal in hydraulic dredging.

(2) The deeper the digging depth, the higher the sediment content. For a digging depth of 0.5 m, sediment content amounts to about 24%.

(3) The finished surface after dredging is rugged and uneven.

(4) A digger with a suction shape is not suitable for superficial sediment removal.

In the next stage an improved digger form was developed as shown in Figure 8.

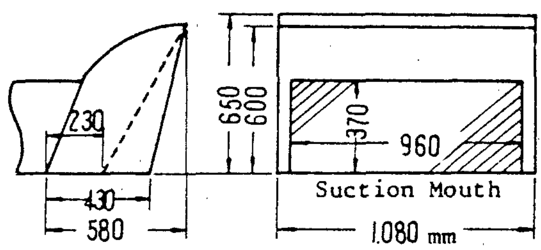


Figure 8. Improved digger

The test results demonstrate a good applicability for thin layer dredging, having the following points:

(1) Sediment content increases according to swing speed, but converges at some final value. This may result from the fact that some sediment moves away from the side of the digger (Figure 9).

(2) Removal efficiency decreases according to swing speed. For higher removal efficiencies, a lower swing speed is desirable. However, doing so increases water content and lowers removal efficiency (Figure 10).

(3) For an open edge type digger, some water enfolding is unavoidable in a swing system.

(4) Digger forms have their own performances with variances according to sediment properties such as viscosity, specific gravity, and soil strength.

Dredging Operations

During dredging, the dredge advances with one cut of 1.1 m, striking the main and auxiliary spuds so that no upper sediment layers remain (Figure 11).

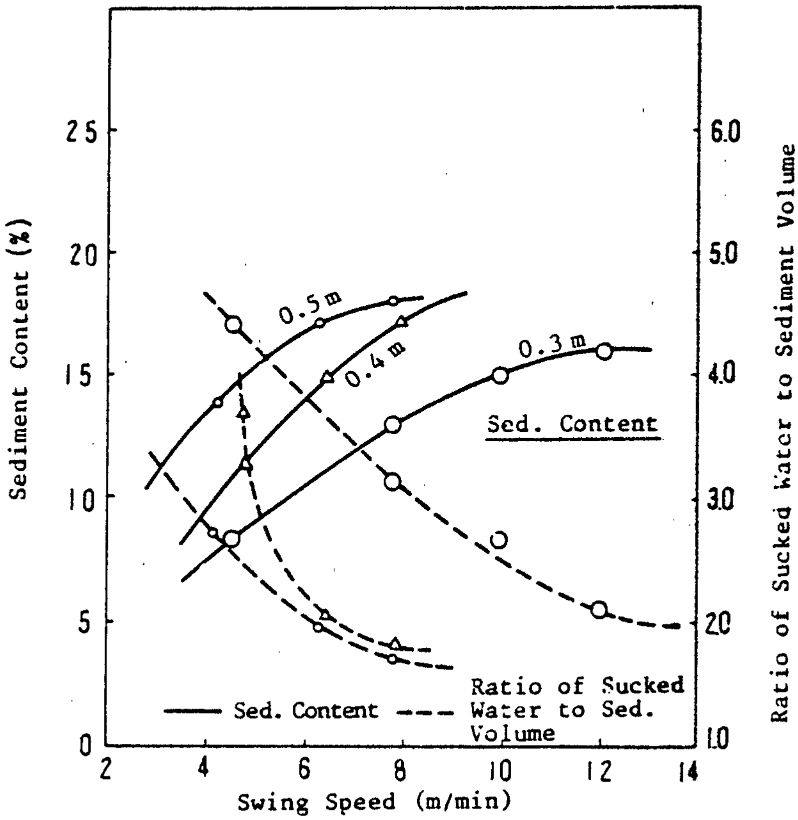


Figure 9. Relationships between swing speed and sediment content

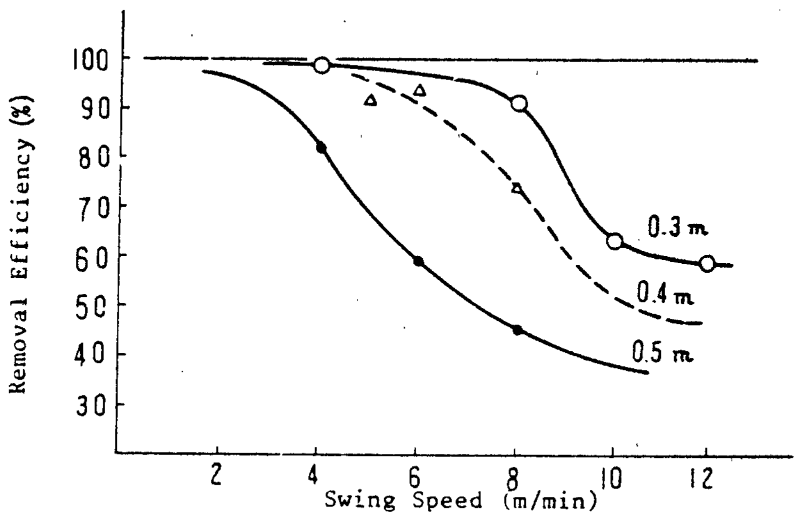


Figure 10. Relationship between swing speed and removal efficiency

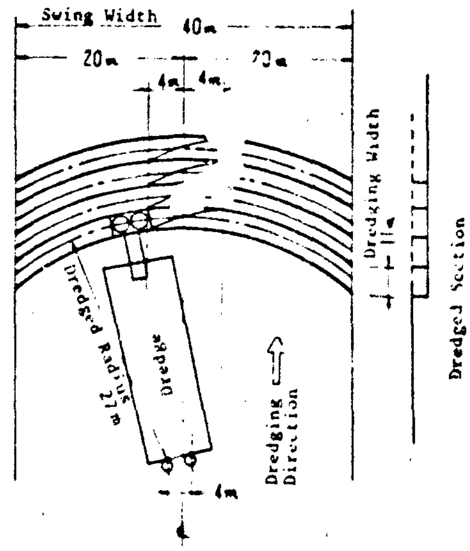


Figure 11. Dredging operation

Two swing speeds are possible, one for digging and one for cleaning, to avoid excess water. As shown in Figure 12, the results monitored by sound waves indicate a relatively smooth surface with this method.

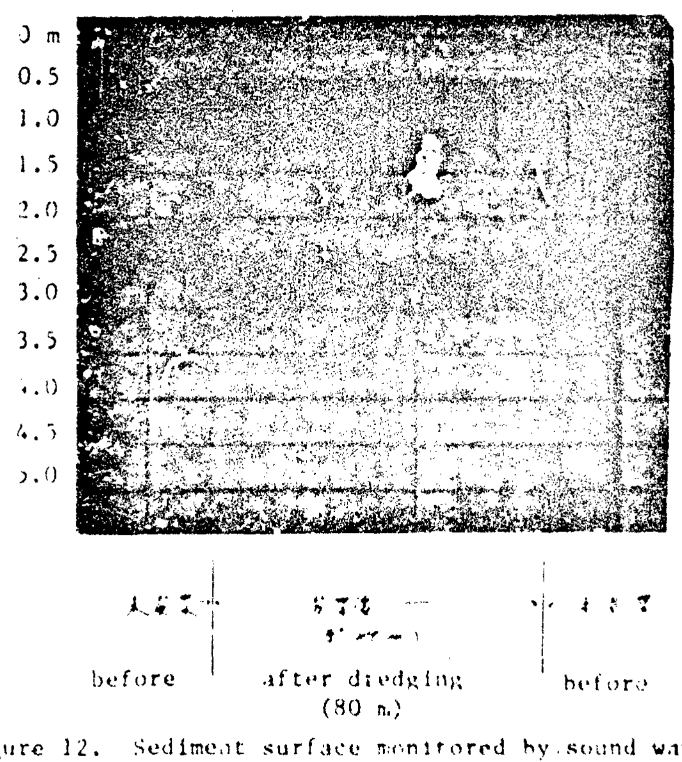


Figure 12. Sediment surface monitored by sound wave

Relation Between Sediment Volume and Discharged Water Quantities

According to our dredging experiment the relationship between sediment volume and discharged water quantity is described by the following formula:

$$Q = \zeta_1 \zeta_2 Sh (1 + \alpha)$$

where

Q = discharged water quantities, m^3

ζ_1 = surplus water efficiency (sucked water eff.), 1.8 - 2.1

ζ_2 = removal efficiency, 0.8 - 0.9

$= \dfrac{\text{actual dredged quantities}}{\text{planned quantities}}$

S = dredged area, m^2

h = dredged height, m

α = excess sediment

MANAGEMENT OF DREDGING WORK

Present State of Sediment Pollution and Its Removal as a Restoration Measure

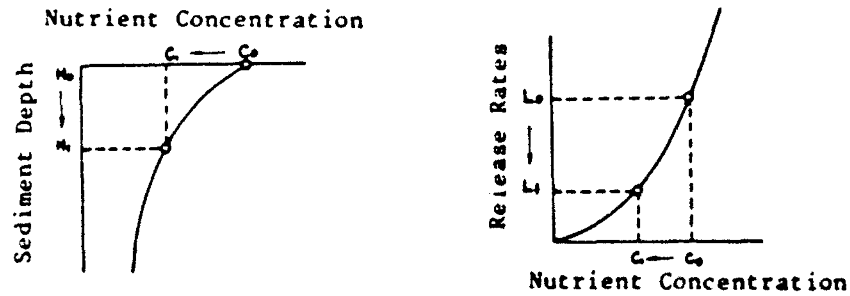
Dredging is thought to reduce the release of loads through sediment removal, which may contribute to improved water quality.

As Figure 13 shows, sediment in Kasumigaura is polluted to a large extent in its upper layers with little pollution occurring in lower ones. An exponential relationship seems to exist between nutrient concentrations and release rates. Therefore, if sediment removal from H_0 to H_1 is conducted, the pollutants in the sediment decrease from C_0 to C_1 and release rates decrease from L_0 to L_1.

Figure 14 shows the vertical distribution of total phosphorus (T-P) in sediment against sediment depth. From this we can say that, for an effective improvement of water quality, it is desirable to dredge the widest possible area even if only a small thickness is removed.

Purpose and Subject of Dredging

Dredging currently under way is aimed at improving water quality. It differs from maintenance dredging for water depth, or protecting blockades in estuaries.



a. Vertical distribution of nutrient concentration

b. Release rates gain nutrient concentration

Figure 13. Vertical distribution of nutrient concentrations and released rates against them

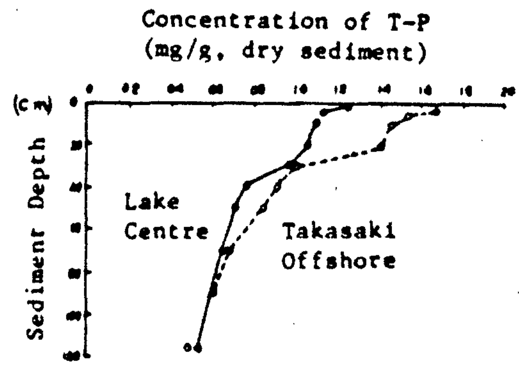


Figure 14. Vertical distribution of T-P in sediment

Water quality dredging differs in the following ways:

(1) A small thickness of sediment may have to be dredged according to sediment conditions. Water depth is also small.

(2) It is difficult to estimate the sediment volume dredged because sediment volumes are largely a function of working conditions.

Results of Dredging

The dredged quantities of sediment to date are as follows:

1975	4,000 m^3
1976	18,000 m^3
1977	13,000 m^3

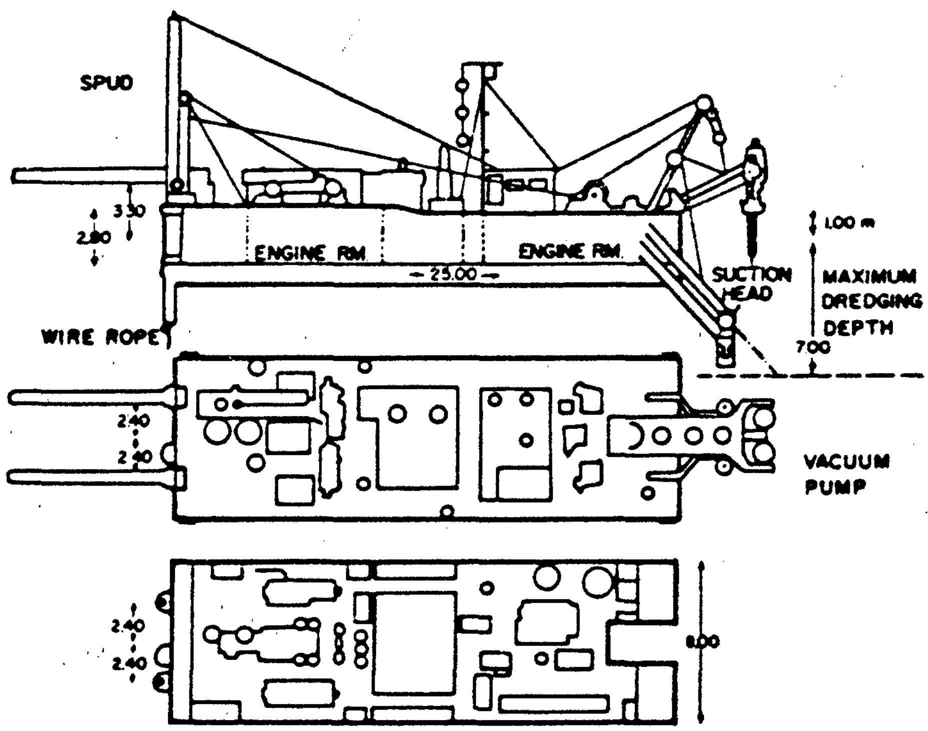


Figure 15. General view of the dredge KŌRYI'

1978	34,000 m^3
1979	40,000 m^3
1980	85,000 m^3
1981	106,000 m^3
	300,000 m^3

Problems on Work Confirmation

Problems with work are as follows:

(1) Due to the shallow water depth, the guidelines on "sediment quantities" defined by "civil work common specifications" cannot be applied.

(2) As the water content of sediment is high and the sediment volume by working conditions varies greatly, it is difficult to estimate the sediment volume dredged.

(3) Sediment removal in the upper layers must be controlled.

(4) The guidelines for work confirmation are not always clearly defined.

(5) Sediment content changes largely according to dredging operations.

There are four ways to check sediment volume. Measure the discharged quantities of the delivery pump, estimate planned values, measure the management ponds, and measure transported quantities. These four methods give very different results. To solve these problems, the investigations discussed in the following section were conducted.

Checking Dredged Sediment Volume

Dredged sediment volume changes greatly according to water content (Figure 16). In checking this volume, the following conditions should be considered:

(1) Sediment is at the lake bottom in a state consolidated by natural accumulation.

(2) In hydraulic dredging, water content becomes high and discharged liquid quantities large because water is sucked along with sediment.

(3) The water content and sediment volume in dredged material settled in the management pond vary with rainfall and evaporation.

Three calculations of sediment volume are conventionally conducted:

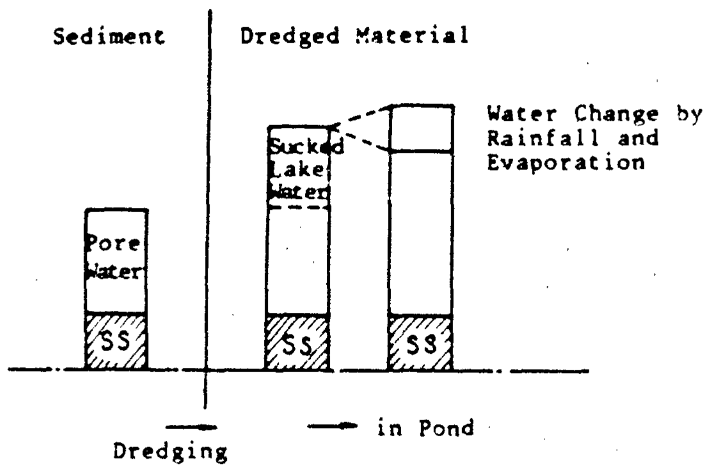


Figure 16. Solid and liquid content of sediment

$$M_1 = V_1 \times \frac{100Gs}{100 + GsW_1}$$

$$M_2 = V_2 \times \frac{100Gs}{100 + GsW_2}$$

$$M_3 = V_3 \times \frac{100Gs}{100 + GsW_3}$$

where

V_1 = sediment volume at the bottom, m^3

V_2 = discharged water volume, m^3

V_3 = sediment volume in management pond, m^3

M_1 = dry weight of sediment at the bottom, tons

M_2 = dry weight of discharged water quantities, tons

M_3 = dry weight of sediment settled in the pond, tons

W_1 = water content at the bottom, %

W_2 = water content of dredged liquid, %

W_3 = water content in management pond, %

Gs = specific weight of sediment solid, tons/m^3

The advantages and disadvantages of these calculations are indicated in Table 1.

Table 1

Merits and Demerits of Sediment Volume Checking

	Merits	Demerits
V_1	(1) Sediment volume is removed from the lake bottom (2) Dredging is conducted generally on the basis of sediment volume at the bottom	(1) Survey errors are large (2) Sediment volume cannot be estimated before work completion (3) It cannot be checked for progress (4) In future dredging of sediment with high water contents, sediment in the already dredged area may collapse
V_2	(1) It can be taken for sediment volume, which has passed through the delivery pump (2) It is easy to control by digital displays (3) Control results can be directly reflected in the progress (4) Net working hours are controlled by charts (5) Sediment contents are controllable by charts	(1) Adjustment with a flowmeter is necessary (2) Adjustment by measuring the sediment content is necessary (3) Troubles with flowmeters may occur
V_3	(1) It is easy to measure (2) Management ponds can be utilized for other purposes	(1) Sediment volume changes every day by rainfall

The data which were obtained by measuring these volumes from 1978 to 1981 are listed in Table 2.

Table 2

Counted Values by Three Checking Methods

	Sediment Volume (m^3)			Sediment Dry Weight (t)		
	Sediment Removed (m^3)	Discharge Water Quantities (m^3)	Quantities Settled in Pond (m^3)	Sediment Removed (tons)	Discharge Water Quantities (tons)	Quantities Settled in Pond (tons)
1978	17,227	35,615	29,960	9,027	9,545	9,248
1979	23,418	39,009	33,278	11,592	11,586	10,574
1980	47,270	81,073	78,810	26,090	26,757	25,287
1981	38,500	86,800	77,300	14,660	15,400	14,580
Remarks	Counted by soil survey before and after dredging	Counted by measuring apparatus in dredge	Measured in pond	Counted by soil survey before and after dredging	Counted by measuring apparatus in dredge	Measured in pond
	V_1	V_2	V_3	M_1	M_2	M_3

BOUNDARY CONDITIONS OF SEDIMENT SURFACES VIEWED FROM DO BEHAVIOR

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ABSTRACT

In measurement of dissolved oxygen (DO) stratifications, the lowest point is chosen usually at a depth of 0.5 m above the sediment surface. DO concentrations in the overlying water just above the sediment are rarely measured. Therefore, the DO behavior in the sediment-water interface is not well known. In order to investigate DO behavior, column tests on DO were performed by use of special test apparatus. This paper deals with these test results and discusses the boundary conditions of sediment-water interface on DO behavior.

OUTLINE OF TESTS

The test column consists of two parts: the upper and lower sections. The latter is the column sampler itself, which has been used for sampling undisturbed sediment. Both tubes are connected by a ring coupling in the laboratory (Figures 1 and 2).

The connected test column is then provided with water jackets at its circumference and erected in an isothermal tank. In order to emerge from a thermal stratification in summer lake water, the overlying water column is heated by three isothermal tanks with different temperatures. Since we had to measure DO concentrations of very thin layers, we have paid close attention to water sampling and analysis.

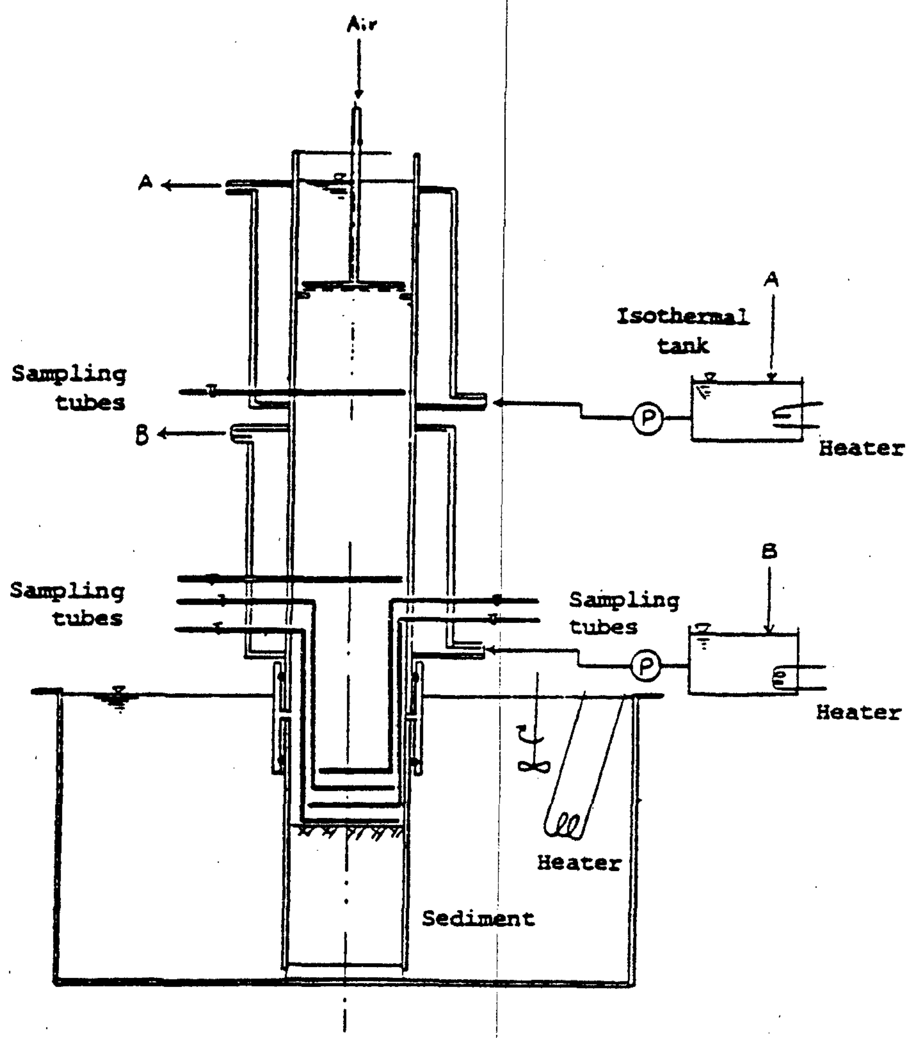

Figure 1. Test apparatus

The sampling tube (Figure 3) has a diameter of 6 mm, a horizontal length of 170 mm, and 8 holes of 0.5 mmϕ. In the 1980 tests, 4 tubes were inserted at heights of 1, 10, 40, and 70 cm above sediment, and in the 1981 tests, 6 tubes at heights of 1, 4, 7, 10, 40, and 70 cm, respectively. The 15-ml water samples were taken gently so that the Reynolds' numbers did not exceed 100. Samples were put into the special DO meter, which was designed for this test (Figure 4). This meter has a small stirrer for medical use and is capable of measuring very small quantities of water.

The sediment samples were taken from Lake Nakanoumi and one of its inflowing rivers.

THERMAL STRATIFICATION

Quantities of heat flowing into and out of a segment of the water column may be expressed as shown in Figure 5.

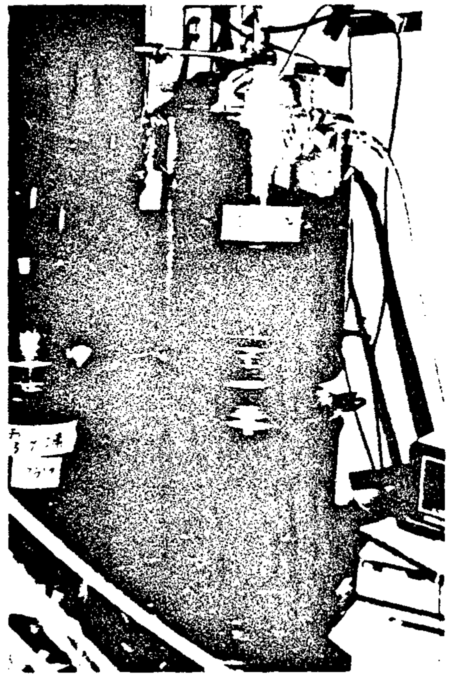

Figure 2. Photo of apparatus

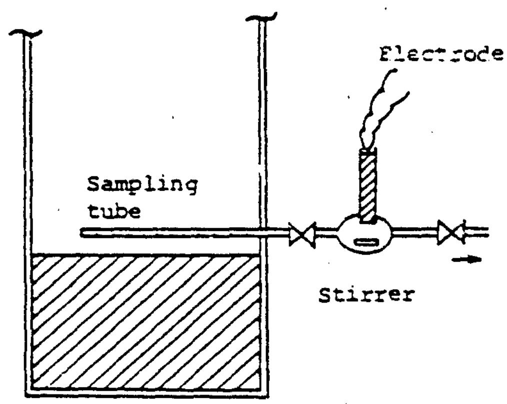

Figure 3. Sampling tube

As equilibrium equation for the heat quantities is represented as follows:

$$\frac{\partial T}{\partial t} = \frac{k}{Cp} \frac{\partial^2 T}{\partial z^2} - wT \frac{\partial \rho}{\partial z} - \rho w \frac{\partial T}{\partial z} \tag{1}$$

where

T = water temperature °C

t = time after incubation of tests, days

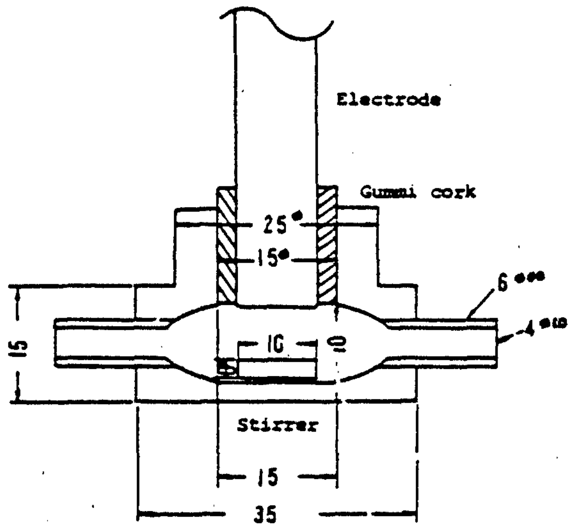

Figure 4. DO meter

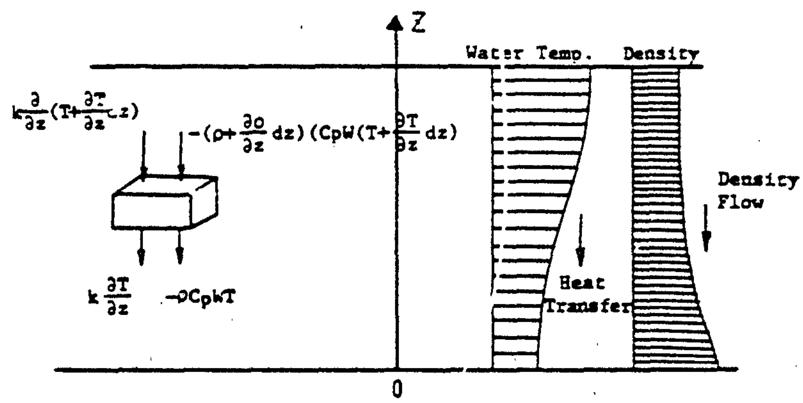

Figure 5. Induction of thermal stratification

w = descending flow velocity due to water temperature difference, cm/sec

Cp = specific heat of water, cal/°C/cm^3

k = thermal conductivity, cal/cm/sec/°C

ρ = water density, g/cm^3

z = height of water column

The solution of Equation 1 is obtained in the following series function:

$$\frac{T}{T_o} = 1 + \frac{W^2}{4D^2} z^2 - \frac{7}{24} \beta^3 W^3 T_o z^3 \qquad (2)$$

where

T_o = water temperature at $z = 0$

ρ_{20} = water density at 20°C

$\rho = \rho_{20}\,(1 - \alpha T)$ is assumed (3)

$$\beta = \frac{\alpha \rho_{20}\, Cp}{k} \qquad (4)$$

D = thermal diffusivity, cm^2/sec

Here we calculate

$$\beta = \frac{\alpha \rho_{20}\, Cp}{k} = \frac{2.55 \times 10^{-4} \times 0.9982 \times 1}{1.42} = 1.793 \times 10^{-4} \quad \frac{sec}{°C\ cm^2}$$

The observed water temperatures are distributed as shown in Figure 6. These are represented in Figure 7 in terms of the ratio of T/T_o.

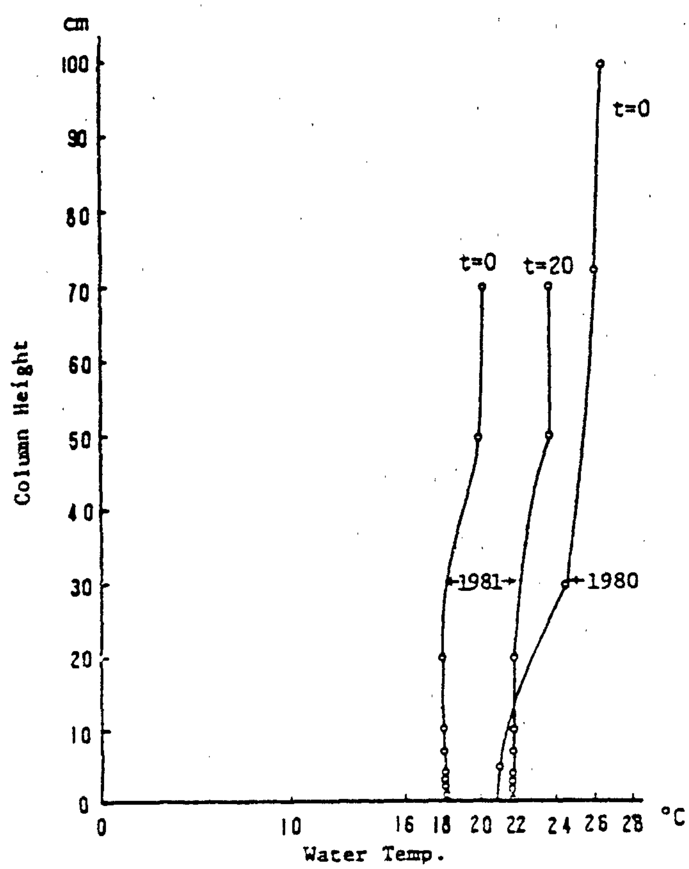

Figure 6. Water temperature distribution

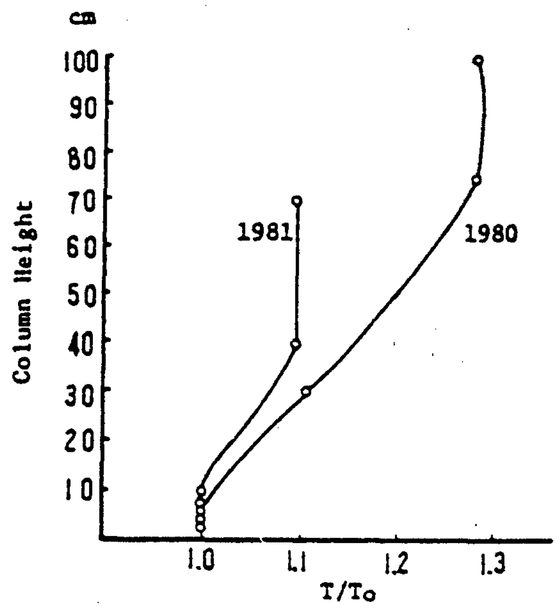

Figure 7. Ratio of T/T_o

Putting the test results $T/T_o = 1.092$ at $z = 40$ cm (1981) into Equation 2, we can calculate the values of w:

$$1.092 = 1 + \frac{w^2}{D^2}\frac{40^2}{4} - \frac{7}{24}(1.793 \times 10^{-4})^3 \times w^3 \times 21.7^3 \times 40^3$$

$$0.092 = 400\,\frac{w^2}{D^2} - 1.0995 \times 10^{-5}\, w^3$$

Neglecting the second term in the right side, we get

$$\frac{w^2}{D^2} = \frac{0.092}{400} = 2.3 \times 10^{-4}$$

$$\frac{w}{D} = 1.517 \times 10^{-2} \quad cm^{-1}$$

Similarly for $T/T_o = 1.1085$ at $z = 30$ cm (1980)

$$\frac{w}{D} = 2.195 \times 10^{-2} \quad cm^{-1}$$

Taking $D = 1.5 \times 10^{-3}$ cm^2/sec, we get

$$w = 1.517 \times 10^{-2} \times 1.5 \times 10^{-3} = 2.276 \times 10^{-5} \text{ cm/sec (1981)}$$

$$w = 2.195 \times 10^{-2} \times 1.5 \times 10^{-3} = 3.287 \times 10^{-5} \text{ cm/sec (1980)}$$

From the water temperature profiles it is found that the descending velocity (w) due to temperature differences at greater differences is about one and a half times as large as at lower differences. (This means that the value of w is proportional to temperature difference. The larger temperature difference, the bigger w.)

VARIANCE OF DO AGAINST TIME

As indicated earlier, sediment samples were taken from Lake Nakanoumi and one of its inflowing rivers. Tap water was used as overlying water.

The relationships between DO concentration profiles and time transfer are shown in Figures 8 and 9.

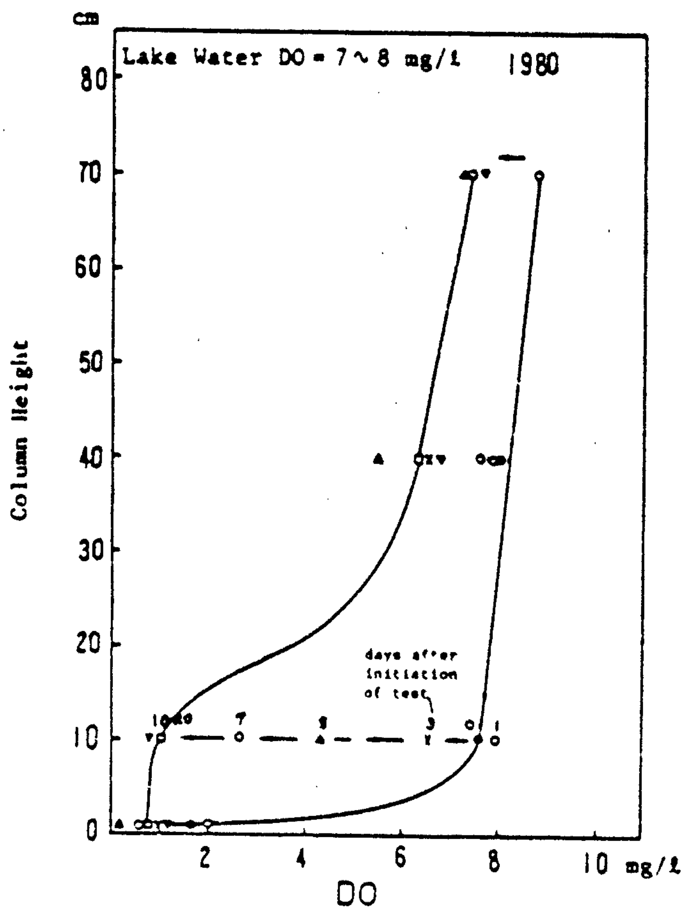

Figure 8. DO stratification

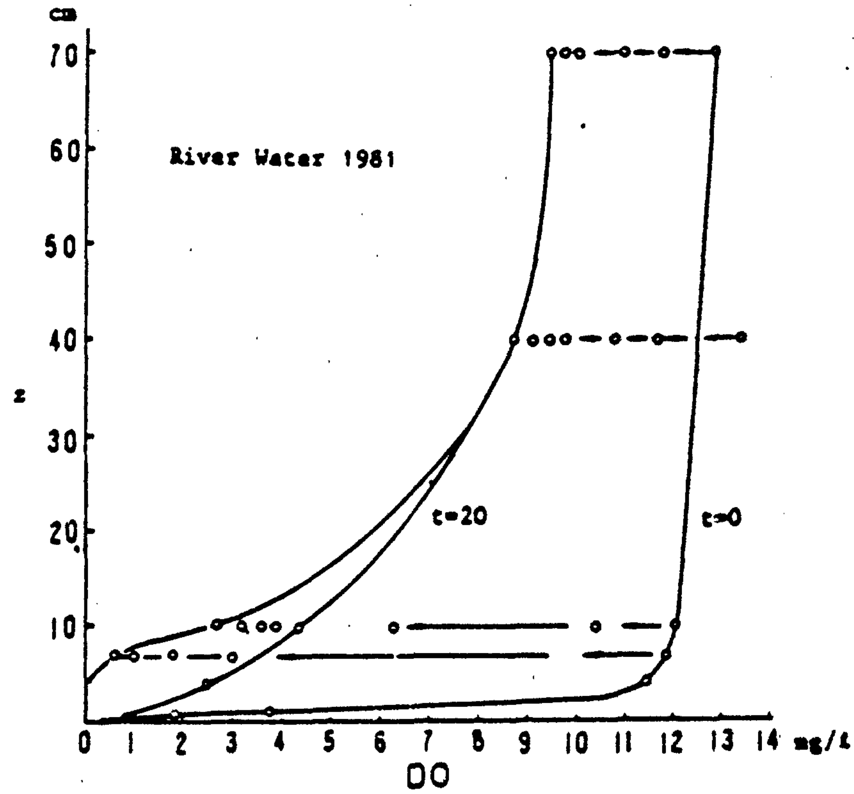

Figure 9. DO stratification

As the figures show, the initial DO profile is a nearly vertical line, located almost entirely in the portion overlying the sediment 10 cm above the interface. DO concentrations decrease rapidly and approach within 10 cm above the interface. We can see clearly that DO concentrations decrease gradually according to time and reach a final distribution shifted to the left in these figures. Their reduction is strong at the lower layers and weak in the upper layers (Figure 10).

DO STRATIFICATION

From our test results, we have learned that we should consider DO stratification in two parts. The first part is the distribution due to thermal stratification occurring in the portion of the water column above the water layer immediately overlying the sediment. The second part is the distribution due to sediment oxygen demand and occurring in the layer immediately overlying the sediment.

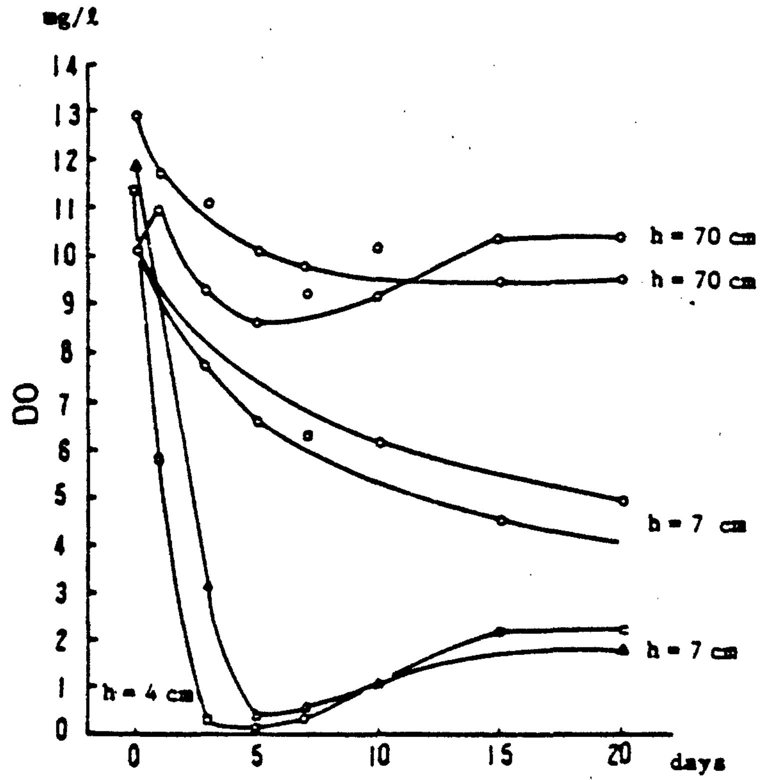

Figure 10. Change of DO against time

DO DISTRIBUTION DUE TO THERMAL STRATIFICATION

An equilibrium equation of disolved oxygen is represented as follows:

$$\frac{\partial c_1}{\partial t} = W \frac{\partial c_1}{Z} - K \frac{\partial^2 c_1}{\partial Z^2} \tag{5}$$

where

c_1 = DO concentration, mg/ℓ

w = descending velocity due to thermal stratification, cm/sec

K = diffusion coefficient of dissolved oxygen in the vertical direction, cm^2/sec

z = length of water column, cm

t = time, sec

We assume that the solution of Equation 5 is a separate function of temperature (T) at time (t) and z as follows:

$$c_1 = T(t)\,S(z) \tag{6}$$

Then putting

$$\frac{T'(t)}{T} = \frac{W \frac{\partial S}{\partial z} + K \frac{\partial^2 S}{\partial z^2}}{S(z)} = -n^2$$

We get

$$T' = -n^2 T \tag{7}$$

$$K \frac{\partial^2 S}{\partial z^2} - W \frac{\partial S}{\partial z} + n^2 S = 0 \tag{8}$$

From Equation 7

$$T = Ce^{-n^2 t} \tag{9}$$

Equation 8 is rewritten as follows:

$$\frac{\partial^2 S}{\partial z^2} - \frac{W}{K}\frac{\partial S}{\partial z} + \frac{n^2}{K} S = 0 \tag{10}$$

$$\left(D^2 - \frac{W}{K} D + \frac{n^2}{K}\right) S = 0$$

$$m^2 - \frac{W}{K} m + \frac{n^2}{K} = 0$$

$$m = \frac{W}{2K} \pm \sqrt{\frac{W^2}{4K^2} - \frac{n^2}{K}}$$

$$= \frac{W}{2K}\left(1 \pm \sqrt{1 - \frac{4n^2 K}{W^2}}\right)$$

Thereupon

$$S(Z) = C_1 e^{m_1 z} + C_2 e^{m_2 z}$$

Finally

$$c_1 = e^{-n^2 t} \left(C_1 e^{m_1 z} + C_2 e^{m_2 Z} \right) \tag{11}$$

At the water surface (z = H where H = total length of water column), the following condition is composed of

$$wC - K \frac{\partial C}{\partial z} = 0 \tag{12}$$

$$w_e^{-n^2 t} \left(C_1 e^{m_1 H} + C_2 e^{m_2 H} \right) - Ke^{-n^2 t} \left(C_1 m_1 e^{m_1 H} + C_2 m_2 e^{m_2 H} \right) = 0$$

$$\left(w + m_1 K \right) e^{m_1 H} C_1 + \left(W + m_2 K \right) e^{m_2 H} C_2 = 0$$

$$C_2 = \frac{w + m_1 K}{w + m_2 K} \; e^{\left(m_1 - m_2\right) H} C_1$$

Then we get

$$c_1 = e^{-n^2 t} \; C_1 \left[e^{m_1 z} + \frac{w + m_1 K}{w + m_2 K} \; e^{\left(m_1 - m_2\right) H + m_2 Z} \right] \tag{13}$$

This is an equation on DO variance in an unsteady flow.

In a steady flow, the following solution is obtained from the equation:

$$w \frac{\partial c_1}{\partial z} - K \frac{\partial^2 c_1}{\partial z^2} = 0$$

$$c_1 = C_1 \frac{K}{w} e^{\frac{w}{K} z} \tag{14}$$

The curve of Equation 13 or 14 is connected to the curve of the deoxygenating zone, which is dealt with in the next section. Consequently, the arbitrary constant C_1 is determined by it. Then,

$$|c_1|_{z=h} = |c_2|_{z=h} \tag{15}$$

$$C_1 \frac{K}{w} e^{\frac{w}{K}h} = C_0 \frac{\sin\left(\sqrt{\frac{\gamma}{K}} + a\right)}{\sin a}$$

$$C_1 = C_0 \frac{w}{K} e^{-\frac{w}{K}h} \frac{\sin\left(\sqrt{\frac{\gamma}{K}}h + a\right)}{\sin a} \tag{16}$$

DISTRIBUTION DUE TO THE DEOXYGENATION OF SEDIMENT

The test results showed that the water temperature in the water just above the sediment ($z \leq 10$ cm) is constant (Figure 11). This means that there is no descending velocity due to thermal stratification. The variance of DO concentrations at this portion is represented as follows:

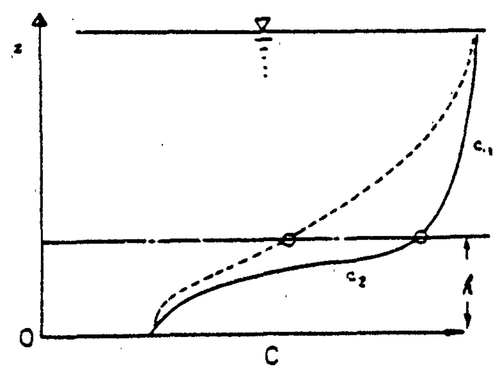

Figure 11. DO distribution in deoxygenating zone, c_1 = DO distribution due to thermal stratification, c_2 = DO distribution due to sediment O_2 demand

$$\frac{\partial c_2}{\partial t} = -K \frac{\partial^2 c_2}{\partial Z^2} - \lambda c_2 \tag{17}$$

where

c_2 = DO concentration, mg/ℓ

K = diffusion coefficient of dissolved oxygen, cm^2/sec

λ = deoxygenating rate, sec

The solution of Equation 18 is obtained as follows:

$$c_2 = e^{-n^2 t}\left(C_1 e^{i\sqrt{\frac{\lambda-n^2}{K}}\,z} + C_2 e^{-i\sqrt{\frac{\lambda-n^2}{K}}\,z}\right) \tag{18}$$

$$= e^{-n^2 t}\, A \sin\left(\sqrt{\frac{\lambda-n^2}{K}}\, z + a\right)$$

since $C = C_0$ at $t = 0$, $z = 0$, we get

$$A = \frac{C_0}{\sin a}$$

Equation 18 becomes

$$C_2 = C_0\, e^{-n^2 t}\; \frac{\sin\left(\sqrt{\frac{\lambda-n^2}{K}}\; z + a\right)}{\sin a} \tag{19}$$

This is an equation of DO variance at the deoxygenating zone in an unsteady flow. In a steady flow, it becomes as follows:

$$C_1 = C_0\, \frac{\sin\left(\sqrt{\frac{\lambda}{K}}\, z + a\right)}{\sin a} \tag{20}$$

$$\lambda = \frac{11.5 - 0.2}{11.5 \times 3 \times 24 \times 3600} = 3.73 \times 10^{-5}\ \mathrm{sec}^{-1} \tag{21}$$

Putting the data together:

$z = 70$ cm; $C_1 = 8.8$ mg/ℓ ($t = 0$)

$z = 10$ cm; $C_1 = 7.6$ mg/ℓ ($t = 0$)

We get

$$\frac{w}{K} = 0.00244$$

Since w is already known (page 7), then we obtain

$$K = 1.345 \times 10^{-2} \ cm^2/sec$$

From the observed data,

$$t = 0,\ C_2 = 11.5 \ mg/\ell, \text{ and } t = 3 \text{ days; } C_2 = 0.2 \ mg/\ell,$$

we get

$$\sqrt{\frac{\lambda}{K}} = 0.0527 \ cm/sec$$

$$a_0 = 0.025 \ rad$$

$$C_0 = 1.22 \ mg/\ell$$

Figure 12 shows the DO profile in the deoxygenating zone.

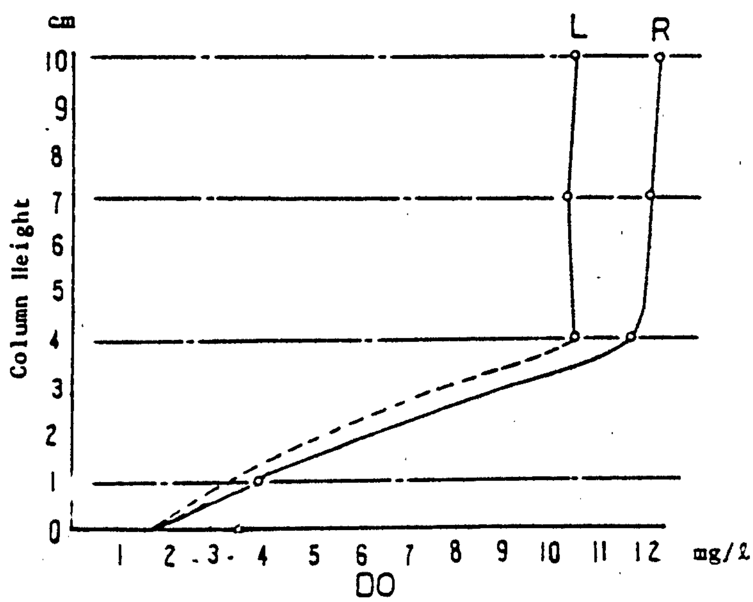

Figure 12. DO profile in deoxygenating zone

BOUNDARY CONDITIONS ON DO AT SEDIMENT SURFACE

As the test results show, we could reemerge DO stratifications in the laboratory. These behaviors were analyzed theoretically in the preceding chapter.

Owing to the DO stratification, the diffusion of dissolved oxygen travels from the upper layers to the lower ones, that is, from higher concentrations to lower ones. The quantities which reach from the top to the sediment surface are $-K \frac{\partial c}{\partial z}$ per unit area and per unit time. On the other side, some quantities of oxygen are consumed by sediment during deoxygenation, as far as it is polluted.

These two quantities should be in equilibrium (Figure 13). Then we get the equation if we represent sediment oxygen demand (SOD) as O_2.

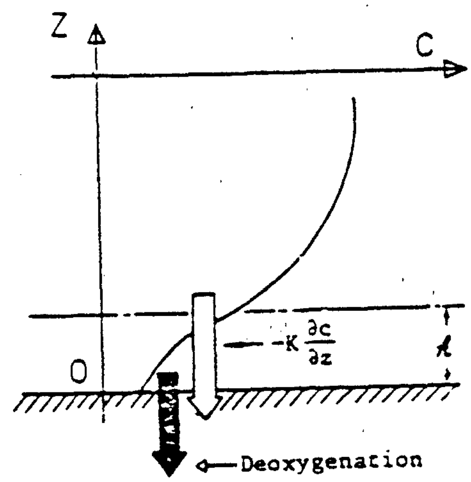

Figure 13. Equilibrium at sediment surface

$$O_2 - \left| K \frac{\partial c}{\partial z} \right|_{z=o} = 0 \tag{22}$$

$$O_2 = K \left| e^{-n^2 t} c_o \sqrt{\frac{\lambda - n^2}{K}} \; \frac{\left(\cos \frac{\lambda - n^2}{K} z + a\right)}{\sin a} \right|_{z = 0}$$

$$= C_o \sqrt{K \left(\lambda - n^2\right)} \cot a \cdot e^{-n^2 t} \tag{23}$$

This is a fundamental equation of SOD. From this, we can say that SOD behaves exponentially against time (Figure 14).

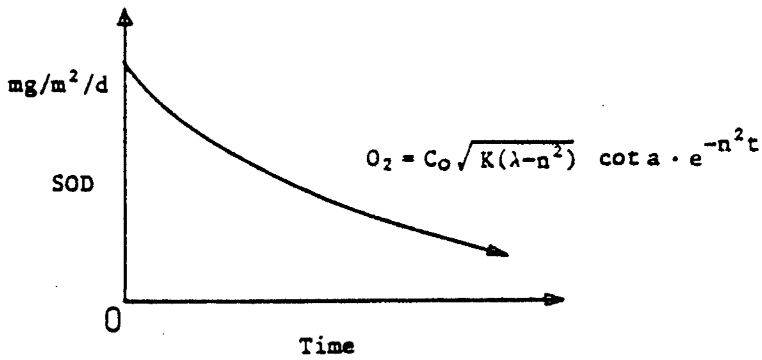

Figure 14. Sediment oxygen demand behavior against time

The total consumption of oxygen (Figure 15) is obtained by a planimeter. If we represent it mathematically, it becomes

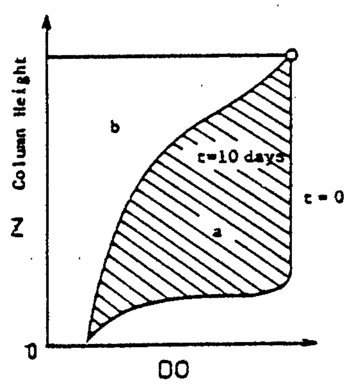

Figure 15. Total consumption of oxygen

$$Q = \frac{1}{AH}\left[\int_0^H c(t = o)\,dz - \int_0^H c(t)\,dz\right]$$

In Table 1, the measured and calculated values of SOD in one sample are indicated. The calculated values are obtained from the assumption that $n^2 = 0.11$.

Table 1. Measured and calculated values of SOD

t	SOD $mg/m^2/d$	$O_2/O_2(0)$ Measured	$O_2/O_2(0)$ Calculated
0	400	1.0	1.0
2	320	0.8	0.803
4	250	0.625	0.644
6	210	0.525	0.517
8	150	0.375	0.375

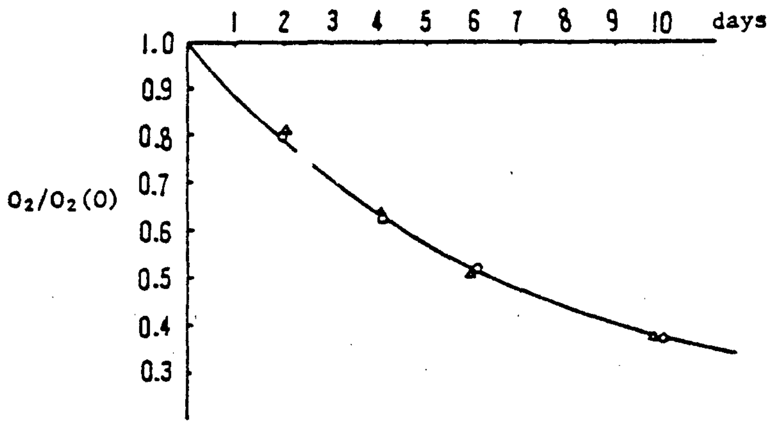

Figure 16. Comparison of measured and computed values of SOD

We can see from Figure 16 that there is a good agreement between observed and calculated values of SOD.

CONCLUSIONS

The DO stratifications that are often observed in lakes and other water areas are well known to pollution investigators. However, there are very few data regarding DO behavior on the sediment surface. From our test results, we can say that the sediment surface is always subject to an anoxic condition owing to its oxygen demand.

From our tests, we have learned that any DO stratification consists of two parts, that is, one due to thermal stratification and one due to the oxygen demand of the sediment. It was also found that the latter has a small height ($z \leq 10$ cm).

In winter, no thermal stratification occurs. Consequently, the DO profile becomes a vertical straight line in most of the water column. In this case, it can incorrectly be considered to extend to the sediment surface.

The line bends at a large angle at the junction with the deoxygenating zone (Figure 17).

DO stratification generated in summer reveals an exponential profile

represented by $$c_1 = C_1 \frac{K}{w} e^{\frac{w}{K}z}$$

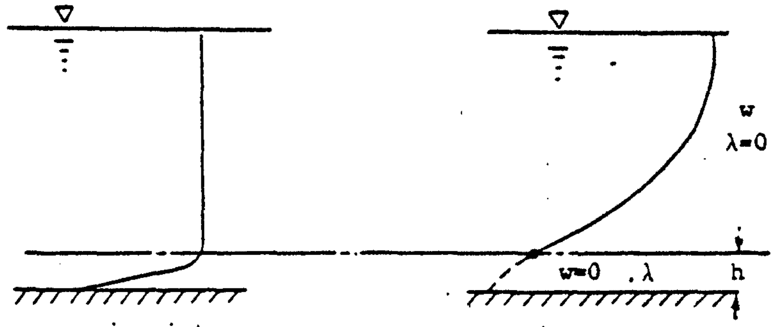

Figure 17. DO profile

This curve is pulled to lower concentrations (to the left in the figure) at its lower end by the curve of the deoxygenating zone.

In our tests, we studied SOD behavior from both observation and theoretical considerations. We found that such DO behavior on the boundary layer of the sediment has a great effect upon the release mechanism of nutrients. However, this problem was not within the scope of this paper.

FIELD VERIFICATION OF TESTING AND PREDICTIVE METHODOLOGIES FOR EVALUATING DREDGED MATERIAL DISPOSAL ALTERNATIVES

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ABSTRACT

This paper describes the research approach being used in the Interagency Field Verification of Testing and Predictive Methodologies for Evaluating Dredged Material Disposal Alternatives Program (Field Verification Program - FVP). Evaluative techniques are being conducted on sediment samples collected from the channel prior to dredging. The same parameters will be measured in the field after disposal takes place. The accuracy of the laboratory predictions will be determined, and the ecological importance of the parameters measured will be assessed. This information will help shape the implementation of the environmental reg·'ations governing dredging and disposal.

INTRODUCTION

Environmental regulations in the United States require that proposed dredged material discharges be evaluated, found acceptable, and a permit issued before the dredging operation can begin. The U.S. Army Corps of Engineers (Corps) is the regulatory agency which issues these permits after evaluating the discharge according to guidelines and criteria established by the U.S. Environmental Protection Agency (EPA). Section 404 of the Clean Water Act (Public Law 92-500) and Section 103 of the Marine Protection, Research and Sanctuaries Act (Public Law 92-532) require that environmental evaluations of dredged material discharges include the effects of disposal on pollutant "concentration through biological processes" (bioaccumulation); "transfer through biological processes" (biomagnification); "effects on fish, shellfish, wildlife, shores, and beaches;" "transfer through physical processes" (sediment transport); "species and community population changes;" and "other locations and methods of disposal including land-based alternatives." At present, some of these evaluations are made using first-generation techniques which have not been field verified and therefore generate data whose interpretation is subject to disagreement. Other of these evaluations, such as effect on wildlife, shores, and beaches; transfer through biological processes; species changes; and alternative disposal methods, are addressed only in a rather cursory and subjective manner because no objective evaluative procedures have been documented or verified.

In order to uphold legal responsibilities, it is necessary to provide Corps and EPA field offices with documented and verified procedures for all the required evaluations. These must be accompanied by interpretive guidance based on documented evidence in order to satisfactorily meet field needs.

The Corps, and to a lesser extent the EPA, have conducted and will continue to conduct the essential first steps of research and development of theoretically sound and practical evaluative techniques. For those techniques that have been developed, it is essential for their acceptance by other regulatory and resource agencies to document and verify under field conditions both the accuracy of the techniques and the overall environmental consequences of the predicted changes. The Field Verification Program (FVP) meets this critical need. The program is a cooperative effort between the Corps and EPA and will be completed within a 5-year period. The program is designed to provide the field with verified procedures and interpretive guidance for use in assessing the environmental consequences of dredged material disposal under aquatic, wetland, and upland conditions. The Waterways Experiment Station (WES), Vicksburg, Mississippi, is the Corps laboratory responsible for the program and will conduct the wetland and upland portions of the program. EPA's Environmental Research Laboratory at Narragansett, Rhode Island (ERLN), is the responsible EPA laboratory and will conduct the majority of work for the aquatic portion of the program.

PROGRAM OVERVIEW

The purpose of the program is to document and verify existing predictive techniques for use by the field in evaluating the long-term effects of dredged material disposal. This will be accomplished by achieving three primary objectives. One is to demonstrate the adaptability of a variety of existing predictive techniques to dredged material, and to determine the reproducibility of those techniques in the laboratory. The second objective is to utilize field studies to verify the accuracy of the laboratory predictions. The third major objective is to utilize the laboratory and field data to compare disposal in upland, wetland, and aquatic environments in terms of overall impact. To accomplish the program objectives, evaluation techniques previously developed by both the Corps and EPA will be applied to the routine maintenance dredging of Black Rock Harbor, Bridgeport, Connecticut. Portions of the relatively homogeneous dredged material from this project will be placed in an aquatic disposal site, used to create a wetland, and placed in an upland confined disposal site. This will provide the unusual opportunity to verify evaluative techniques for predicting impacts in all three types of disposal environments and allow a direct comparison of the environmental consequences of the same material under different disposal conditions.

For management purposes, the program has been divided into Aquatic, Upland, and Wetland areas of investigation. Work units that address specific topics were developed within each major area of investigation. Each work unit includes both the laboratory documentation of the applicability, reproducibility, and precision of the technique(s), and the field verification of its accuracy in predicting the environmental consequences.

The results of the Aquatic, Upland, and Wetland areas of investigation will be published throughout the program in scientific journal articles and a comprehensive series of Technical Reports, as listed in Table 1. The information generated in all areas of investigation will be used to develop a program synthesis report. This report will delineate the usability of techniques along with interpretive procedures for accurately predicting environmentally important consequences from the disposal of dredged material under aquatic, wetland, and upland conditions.

The FVP was authorized and funded in February 1982. In April, with the cooperation of the New England Division of the Corps, predredging sediments were collected for physical and chemical characterization and for use in laboratory predictive testing. A technical agreement between the WES and ERLN was developed and signed. This agreement delineates the responsibilities of the respective laboratories for the aquatic portion of the program. ERLN has initiated the aquatic biological studies while the WES has initiated the upland and wetland plant and animal bioassay laboratory studies. In addition, the design for the confined disposal site and predictive testing for effluent quality have been completed. Baseline data surveys of the aquatic disposal site were conducted by ERLN during the summer. The FVP has been presented to Federal and state resource agencies and the public through public meetings, workshops, and briefings.

The confined disposal site will be constructed during the winter of 1982. Disposal operations at the confined disposal and aquatic sites will be conducted during the spring and summer of 1983. Laboratory documentation of testing procedures for bioaccumulation and consequences of bioaccumulation in aquatic organisms will continue through 1983. Results of these laboratory studies will be reported in 1984 and 1985, through Technical Reports, Newsletters, and scientific journal articles. Field verification of the laboratory results at the aquatic disposal site will start in 1983 and continue into 1985, with results of the field studies reported in 1986. During dredged material disposal at the confined disposal site, water quality will be monitored for use in verifying laboratory predictions. After disposal, surface runoff and groundwater will be monitored for determining potential contaminant movement. Laboratory bioassay testing with upland and wetland plants and animals will continue through 1983, with field verification studies commencing in 1983 and continuing into 1985. Results of the upland and wetland laboratory and field studies will be reported in 1984-86. Calibration and verification of a three-dimensional (3-D) sediment transport model will be completed and a User Guidance Manual will be available in 1983. A workshop on uses of the sediment transport model will be held in late 1983.

The major effort for 1986, the last year of the program, will be the technical transfer of the program results. User-oriented products, primarily in the forms of Technical Reports and Engineering Manuals, will be developed. These documents will provide the field with documented and verified techniques and interpretive guidance for complying with regulatory requirements for evaluating dredged material. The scientific documentation necessary to demonstrate the appropriateness of the recommendations will be established by publication of findings in the scientific literature.

The Corps and EPA share responsibility for the regulatory program for dredged material. Experience has proven that cooperation at the field working level is greatly enhanced when scientists of both agencies jointly recommend the same evaluative procedures. The FVP should produce similar increased cooperation at higher levels by uniting the agencies in purpose and funding at the Laboratory-Division-Region level. This will add to the credibility of the program among critics and reduce any perceptions of bias.

PROGRAM IMPLEMENTATION-AQUATIC

The Aquatic area of investigation includes four work units. The work unit entitled "Bioaccumulation of Contaminants by Aquatic Animals" will document the laboratory reproducibility and precision of available bioaccumulation predictive procedures, and verify the accuracy of the predictions under field conditions. The second work unit, entitled "Consequences of Bioaccumulation in Aquatic Animals," will evaluate selected physiological response parameters as indicators of the biological consequences of bioaccumulation and verify these procedures under field conditions. These parameters have been developed by EPA for evaluating effects on fish and shellfish for nondredged materials. Included in these parameters are: scope for growth (metabolic potential for growth and reproduction), genetic toxicology (sister chromatid exchange), histopathology (deformities, abnormalities, and diseases), and changes in adenylate energy charge. Also included in the work unit is the incorporation of these and other measurements into a hazard assessment protocol for overall impact prediction and assessment. The third work unit, entitled "Effects of Aquatic Disposal on Community Structure," will determine potential impacts of contaminated dredged material on populations and community structure and function in the laboratory and evaluate the effects of open water disposal on populations and communities in the field. The fourth work unit, entitled "Dredged Material Movement," involves the completion of calibration and verification of a 3-D mathematical model for simulating the dispersion of dredged material from aquatic disposal sites.

Bioaccumulation of Contaminants by Aquatic Animals

Problem

National legislation and international treaty require an assessment of bioaccumulation. The reproducibility of test results and precision of bioaccumulation predictions made using the current regulatory procedure have never been determined, nor has the accuracy of the procedure in predicting actual field conditions been assessed. This information is essential in order to properly interpret test results in a regulatory context and to determine whether alternate or modified procedures evaluated in other work units are more useful.

Objective

The objective of this work unit is to document the laboratory reproducibility and precision of available bioaccumulation predictive procedures, and to verify the accuracy of the predictions under field conditions.

Approach

Existing evaluative techniques will be refined as necessary and their predictive value verified by applying them to this specific dredging project. Levels of bioaccumulation of selected contaminants over time, the biological and physical factors affecting bioaccumulation, and the variability in bioaccumulation predictions will be documented in the laboratory. Bioaccumulation will then be determined under field conditions and compared with laboratory predictions to verify the accuracy of the prediction methodologies.

Initial characterization of Black Rock Harbor sediments has been completed. Baseline body burdens in organisms collected at the aquatic disposal site were determined prior to disposal operations. Bioaccumulation of contaminants present in the sediment by a number of indigenous aquatic species has been documented in the laboratory. Species examined include the mussel Mytilus edulis, the polychaete worm Nephtys incisa, and the crustacean Mysidopsis bahia.

Laboratory documentation of bioaccumulation will be expanded to include additional exposure conditions and species such as the winter flounder Pseudopleuronectes americanus and the polychaete worm Neanthes arenaceodentata. Work will be initiated to field verify the bioaccumulation procedures at the disposal site receiving contaminated dredged material. Chemical analysis of contaminants associated with suspended sediments will be carried out. Emphasis will be on the comprehensive field verification of bioaccumulation procedures. Bioaccumulation from suspended sediments will be compared with that from consolidated sediments. Chemical analysis of dredged material after disposal will be carried out.

Consequences of Bioaccumulation in Aquatic Animals

Problem

Dredging operations may result in the accumulation of toxic substances by aquatic organisms. There is presently no means of assessing the biological significance of these observed body burdens. This capability is required by Corps and EPA field personnel to evaluate the impact of dredging operations on aquatic organisms as mandated by national legislation and international treaty.

Objective

This work unit objective is to evaluate selected physiological response parameters as indicators of the biological consequences of bioaccumulation and to verify these procedures under field conditions.

Approach

Several physiological indices of biological health will be determined in organisms which have accumulated environmental contaminants from dredged material. These indices will include: scope for growth, sister chromatid exchange, adenylate energy charge, and histopathological parameters. These responses will first be determined in the laboratory to establish feasibility

of use with dredged material and correlation with bioaccumulation. They will then be verified in aquatic organisms exposed to contaminated sediments in the field. In addition, there will be an overview of the consequences of bioaccumulation by integrating the results of all investigations within the program on the effects of open water disposal. This synthesis will qualitatively and quantitatively evaluate the methodologies used to assess the consequences of bioaccumulation at the three levels of biological organization (i.e. population/communities, individual organisms, and biochemical) and to relate these methodologies with observed levels of tissue contamination.

Baseline data on scope for growth, sister chromatid exchange, adenylate energy charge, and histopathology were collected prior to disposal operations. Animal studies include the mussel Mytilus edulis, the polychaete Nephyts incisa, and the amphipod Amplisca abdita. Laboratory documentation of physiological indices of biological stress will be expanded to include the worm Neanthes arenaceodentata and the crustacean Mysidopsis bahia. The response of the indices will be documented in animals exposed to suspended as well as consolidated sediments. Work will be initiated to evaluate the use of these physiological responses as indicators of biological health following actual disposal operations in the field. Emphasis will be on field verification of potentially useful biological responses. Field verification of laboratory observed physiological indices of health will be conducted. Physiological response will be correlated with contaminant body burdens for regulatory use.

Effects of Aquatic Disposal on Community Structure

Problem

Comprehensive evaluation of aquatic disposal impacts requires that, in addition to studies using selected key species, communities also be evaluated. This work unit will evaluate the usefulness of existing procedures for predicting effects on communities, and determine the actual effects occurring in the field. It is expected that this work will provide a quantitative basis for addressing the requirements under the Ocean Dumping Act and Clean Water Act to assess the effects of disposal on changes in ecosystem diversity, productivity, stability, and species and community population changes.

Objective

The objective of this work unit is to determine potential impacts of contaminated dredged material on populations and community structure and function in the laboratory and to evaluate the effects of open water disposal on populations and communities in the field.

Approach

The effects of contaminated dredged material disposal on community structure will be determined by measuring species diversity, biomass distributions, mortality, reproduction, and the intrinsic rate of growth in selected populations within aquatic communities. These population assessments will be documented in the laboratory and verified by monitoring population and community changes in field environments impacted by contaminated dredged material.

Baseline studies have been carried out to characterize the benthic community and populations in the aquatic disposal area prior to dredging operations. Laboratory studies have been initiated to determine the effects of contaminated dredged material on the population dynamics of the crustacean *Mysidopsis bahia*. Assessment of the effects of aquatic disposal on community structure will begin after dredging operations have been completed. Species diversity and biomass distribution in space and time will be determined at the aquatic disposal site. Laboratory documentation of the population dynamics of *Mysidopsis bahia* will continue over two years. Initial population densities and cohort frequencies of mysids at the disposal site and the effects of aquatic disposal on benthic community structure and succession will be determined. An attempt will be made to correlate changes in population dynamics observed in the laboratory with changes in community structure observed in the field.

Dredged Material Movement

Problem

Funding to begin the development of a three-dimensional mathematical hydrodynamic model was provided by the Corps during 1980-82. Basic model development has been completed and the model applied to a coastal environment. Field data have been collected in conjunction with this effort, but model calibration and verification have not been completed. This research is needed to provide an accurate, reliable, and economical model to simulate 3-D long-wave phenomena and associated transport of dredged material and environmental constituents. Comprehensive models for describing dredged material movements in a coastal environment do not presently exist. Such a model is necessary to assess the potential impact of ocean dredged material disposal by delineating the area of possible impact. It will also allow optimum design of monitoring efforts by indicating the most appropriate sampling locations.

Objective

Completion of calibration and verification of a 3-D mathematical model for simulating the dispersion of dredged material from aquatic disposal sites is the objective of this work unit.

Approach

Calibration and verification of the 3-D dredged material transport model will be accomplished using previously gathered field data and model runs. This will provide a documented, user-ready model which will respond to wind and tide, surface heat and salt flux, river flow, salinity, and temperature and surface elevation specified at open inflow boundaries. Based on the results of the verification, a decision will be made whether further dredged material transport modeling work is required.

At present the 3-D model of sediment transport in aquatic disposal sites has been developed and efforts to calibrate the model using existing field data have been initiated. Calibration and verification of the sediment transport model through repeated model runs will be continued. The limits

and applicability of the model will be established and documented in a User Guidance Manual. A workshop/seminar on the uses of the model will be conducted. Simplified techniques for the application of the sediment transport model to regulatory evaluation will be developed.

PROGRAM IMPLEMENTATION-UPLAND AND WETLAND

The Upland and Wetland areas of investigation include four work units. The first, entitled "Effects of Upland Disposal on Water Quality," will document and verify techniques for prediction of water quality effects of confined dredged material disposal. The second work unit, entitled "Bioaccumulation of Contaminants in Upland and Wetland Plants," will document and verify plant bioassay procedures to predict movement of contaminants into upland and wetland plants. The third work unit, entitled "Bioaccumulation of Contaminants in Upland Animals," will document and verify existing terrestrial animal bioassay procedures to predict bioaccumulation of contaminants in upland animals. The last work unit, entitled "Bioaccumulation of Contaminants in Wetland Animals," will document and verify existing wetland animal bioassay procedures to predict bioaccumulation of contaminants in wetland animals.

Effects of Upland Disposal on Water Quality

Problem

Section 404 of the Clean Water Act requires evaluation of containment area effluent water quality. Techniques to predict effluent quality have been and are continuing to be developed in laboratory studies. However, before use of the techniques by regulatory agencies, field verification under controlled conditions is required. This field study will provide information on the behavior of contaminants entering, moving through, and discharged from confined disposal areas as effluent or surface runoff, and will determine potential for leaching of contaminants into groundwater. Integration of these field results with related research efforts will result in verified techniques for evaluating water quality effects of confined disposal. These verified procedures will improve impact assessment, reduce constraints imposed on confined disposal, and allow meaningful comparison of all available disposal options, resulting in monetary and manpower savings.

Objective

This work unit's objective is to document and verify techniques for prediction of water quality effects of confined dredged material disposal.

Approach

Appropriate laboratory predictive tests will be conducted on contaminated sediments prior to placement in the confined disposal area. Laboratory predictions will be verified by field sampling during the filling operation and surface water and groundwater sampling following the disposal operation.

The confined disposal site has been designed and will be constructed, operated, and managed to ensure adequate sedimentation and optimum fill configuration. Samples from Black Rock Harbor were collected and a variety of laboratory tests conducted to determine settling rates, consolidation rates, and drying rates, and to predict water quality of effluent discharged during the filling operation. In addition, sediment was placed in a soil bed in a controlled environmental building and the drying process monitored. At different soil moisture contents, a simulated rainfall event was applied to the soil bed and the quality of the surface runoff determined. Monitoring wells for determining potential contaminant movement into groundwater were installed at the site, and water samples were analyzed to determine background conditions prior to filling.

Construction of the confinement structure is planned for early FY 83. The confined site will be filled using a small cutterhead dredge. Laboratory predictions of effluent quality will be verified by field sampling at the confined site during the filling operation. Water quality parameters will be monitored extensively in the influent, effluent, and at selected stations within the disposal area. The disposal area will be managed to provide both upland and wetland substrate. Following disposal, the quality of surface water runoff will be determined by controlled simulation of rainfall and collection of surface water samples. Soil erosion control by vegetation will be evaluated. The potential for groundwater contamination will be determined by monitoring wells around and within the disposal area and collection and analysis of groundwater samples taken before and after filling. Surface water quality will continue to be monitored as the sediment is dewatered in the upland portion of the confined site.

Bioaccumulation of Contaminants in Upland and Wetland Plants

Problem

Current legislation under the Clean Water Act, National Environmental Policy Act (NEPA), and Resource Conservation and Recovery Act (RCRA) requires evaluations at or beyond the present state of knowledge and consequently has led to great difficulty, confusion, and ostly project delays for Corps Districts and EPA Regions to properly assess the impact of wetland and upland disposal of contaminated dredged material. An urgent need exists to document and verify existing test procedures for predicting contaminant mobility and bioaccumulation of contaminants in plants under wetland and upland disposal environments.

Objective

The objective of this work unit is to document and verify plant bioassay procedures to predict movement of contaminants into plants grown on dredged material disposal sites.

Approach

Limited work has been conducted and first-generation test procedures have been developed through other research programs to indicate the potential mobility of contaminants from contaminated dredged material under upland

disposal environments. First-generation test procedures will be verified in the field. Bulk samples of sediment from Black Rock Harbor were collected, subsampled, mixed, subsampled, and redistributed to those research laboratories conducting tests. Chemical analyses were performed on the collected sediment samples. Index plants were grown and observed for phytotoxicity during a 90-day growth period.

Field tests will be established at the confined disposal site at Black Rock Harbor. Plants grown in the field tests will be harvested and analyzed for bioaccumulation of contaminants. Field test results will be compared with laboratory tests results for verification of plant uptake prediction. Plants grown during the second year in the field tests at Black Rock Harbor will be harvested and analyzed for any continued bioaccumulation of contaminants. Second year field test results will be compared with the original laboratory tests results and the first year field test results for verification purposes.

Bioaccumulation of Contaminants in Upland Animals

Problem

Section 404 of the Clean Water Act requires that environmental evaluations of dredged material discharge include the effects of disposal on contaminant "concentration through biological processes." Several Corps Districts have indicated a need to predict the contamination of animals that establish residence on upland disposal sites containing contaminated dredged material. Many of these sites have become prolific wildlife habitats despite the highly contaminated dredged material placed within. Districts have indicated a crucial need to be able to predict bioaccumulation of contaminants in animals on these sites before releasing the sites to state and local authorities for their use.

Objective

This work unit's objective is to document and verify existing terrestrial animal bioassay procedures to predict movement of contaminants into animals on dredged material disposal sites.

Approach

Existing upland animal (annelid worm) bioassay test procedures developed by Dr. C. A. Edwards, Rothamsted, England, for the European Economic Community will be applied and verified for use on contaminated dredged material.

Existing techniques for determining bioaccumulation of contaminants in upland animals were reviewed. Technical experts in this area of research were brought to the WES to discuss the most appropriate test procedures to be applied to the Black Rock Harbor sediment. Laboratory bioassay tests were initiated on sediment from Black Rock Harbor using the index animal species *Eisenia foetida* (earthworm).

Field bioassay tests will be initiated at Black Rock Harbor to verify laboratory test results. Annelid worms will be harvested from the upland disposal area and prepared for chemical analyses. Results of the chemical analysis of initial field test animals will be interpreted and field tests will be conducted for the second year. Other animals colonizing the upland site will be collected and analyzed for contaminants. These results will be related to previous laboratory test results with the annelid worm. Field tests with the annelid worm will be conducted for a third year and compared with previous field tests results as well as the original laboratory test results. These results will be used to further verify the laboratory test results.

Bioaccumulation of Contaminants in Wetland Animals

Problem

Section 404 of the Clean Water Act requires that environmental evaluations of dredged material discharges include the effects of disposal on transfer of contaminants through biological processes, i.e., bioaccumulation. There is a substantial lack of knowledge of contaminant bioaccumulation in wetland animals. This inadequate scientific knowledge has led to confusion and costly project delays when Corps Districts and EPA Regions need to assess the impact of wetland habitat creation with contaminated dredged material. An urgent need exists to document and verify existing test procedures for predicting contaminant mobility, bioaccumulation, and biomagnification in animals under wetland disposal environments.

Objective

The work unit objective is to document and verify existing wetland animal bioassay procedures to predict bioaccumulation of contaminants in wetland animals on dredged material disposal sites.

Approach

Potential wetland animal bioassay test procedures will be applied and verified for use on contaminated dredged material.

Existing techniques for determining bioaccumulation of contaminants in wetland animals were reviewed. Technical experts in this area of research were brought to the WES to discuss the most appropriate test procedures to be applied to the Black Rock Harbor Sediment. Laboratory bioassay tests were initiated in sediment from Black Rock Harbor using index animal species Neries sp. (sandworm), Arenicola sp. (lugworm), and Littorina (snail) as suggested by the technical experts. Laboratory bioassay tests will be completed and field bioassay tests will be initiated at Black Rock Harbor to verify laboratory test results. Field tests will continue at Black Rock Harbor to determine bioaccumulation of contaminants in wetland animals during the second year. Other wetland animals that colonize the wetland area will be collected and analyzed for selected contaminants. Second year field test results will be compared with the original laboratory test results as well as the results of the first year field tests. All test results will be evaluated for the verification of laboratory test procedures.

PROGRAM SYNTHESIS

Problem

Section 404 of the Clean Water Act and Section 103 of the Ocean Dumping Act require that environmental evaluations of dredged material discharges include the effects of disposal on "pollutant concentration through biological processes," "transfer through biological processes," "effects on fish, shellfish, wildlife, shores, and beaches," "transfer through physical process," "species and community population changes," and "other locations and methods of disposal including land-based alternatives." In order to uphold legal responsibilities, Corps and EPA field elements require documented and verified procedures for all the required evaluations to accomplish this goal. The results of the FVP will be synthesized into a report that can be used by the field in selecting suitable predictive techniques and interpreting the results.

Objective

The program synthesis objective is to document in a synthesis report the usability of techniques along with interpretive guidance for accurately predicting environmentally important consequences from the disposal of dredged material under aquatic, wetland, and upland conditions.

Approach

The results of the Aquatic, Upland, and Wetland Studies will be used to develop a program synthesis report that delineates those techniques along with interpretive guidance that can be used in assessing the environmental consequences of aquatic, wetland, and upland disposal. Program synthesis will be prepared as a Technical Report. In addition, program results will be transmitted to the public through the preparation and submission of papers to appropriate scientific and technical journals.

PROGRAM APPLICATION

Federal legislation requires the Corps to assess the environmental consequences of dredged material disposal. The availability of documented and verified predictive procedures will provide the quantitative basis needed for compliance with statutory requirements. Impact assessments of disposal alternatives will be improved with verified procedures, resulting in better decision-making and reduced potential for litigation on environmental issues. Another benefit from the program is, with the ability to quantitatively define the environmental consequences of dredged material disposal, unrealistic constraints presently imposed on dredging and dredged material disposal can be eliminated, resulting in monetary and manpower savings. Program results will also provide some of the tools needed for cost-effective dredged material disposal management strategy. Finally, through this program, the Corps can continue to influence the direction of criteria and regulations development and to resolve conflicts with other regulatory and resource agencies.

Results of the program will provide Corps and EPA field offices with documented and verified state-of-the-art techniques and interpretative guidance for complying with the regulatory requirements for dredged material evaluations. Since the work will be conducted jointly by the Corps and EPA, the credibility of the research will be enhanced. The results will be applicable nationwide, and will become available throughout the 5-year program.

TABLE 1. FIELD VERIFICATION PROGRAM MAJOR TECHNOLOGY TRANSFER PRODUCTS

Work Unit	1983	1984	1985	1986
Bioaccumulation of Contaminants by Aquatic Animals	Draft TR/ETL-* Laboratory Documentation of Regulatory Bioaccumulation Procedures (December)			Draft TR-Field Verification of the Precision and Accuracy of Regulatory Bioaccumulation Predictions (March)
Consequences of Bioaccumulation in Aquatic Animals		Draft TR/ETL-Laboratory Determination of Scope for Growth in Aquatic Organisms Exposed to Contaminated Dredged Material (August)		Draft TR/ETL-Consequences of Bioaccumulation as Determined by Field Verified Genetic and Reproduction Assessments (March)
		Draft TR/ETL-Laboratory Determination of Genetic Toxicology and Reproduction in Aquatic Organisms Exposed to Contaminated Dredged Material (August)		Draft TR/ETL-Consequences of Bioaccumulation as Determined by Field Verified Enzyme Parameters (March)
		Draft TR/ETL-Laboratory Determination of Enzyme Systems in Aquatic Organisms Exposed to Contaminated Dredged Material (August)		Draft TR/ETL-Consequences of Bioaccumulation as Determined by Field Verified Histopathological Appraisals (March)
				Draft TR/ETL-Consequences of Bioaccumulation as Determined by Field

(Continued)

* TR = Technical Report; ETL = Engineering Technical Letter.

TABLE 1 (Continued)

Work Unit	1983	1984	1985	1986
		Draft TR/ETL-Laboratory Determination of Histo-pathological Effects in Aquatic Organisms Exposed to Contaminated Dredged Material (August)		Verified Scope for Growth Measurements (March) Draft TR/ETL-Consequences of Bioaccumulation as Deter-mined by Field Verified Histopathological Appraisals (March) Draft TR/ETL-Procedures for Regulatory Evaluation of Aquatic Disposal of Dredged Material (April)
Effects of Upland Disposal on Water Quality	Draft ETL-Containment Area Effluent Quality Field Results (September)	Draft ETL-Surface Water Runoff Quality (March) Draft ETL-Leachate/Groundwater Quality (September) Draft ETL-Disposal Site Design Operation and Management (September)		Draft ETL-Effects of Site Management on Surface Water Quality (April) Draft TR-Synthesis Report on Water Quality Effects of Upland Disposal (April)
Bioaccumulation of Contaminants in Upland and Wetland Plants	Draft ETL-Lab Plant Bioassay Tests (September)		Draft TR/ETL-Field Plant Bioassay Verification (September)	Draft Synthesis Report (April)

(Continued)

TABLE 1 (Continued)

Work Unit	1983	1984	1985	1986
Bioaccumulation of Contaminants in Upland Animals	Draft TR/ETL-Lab Upland Animal Bioassay Tests (December)		Draft TR/ETL-Field Upland Animal Bioassay (September)	Draft TR/ETL-Synthesis Report (April)
Bioaccumulation of Contaminants in Wetland Animals	Draft TR/ETL-Lab Wetland Animal Bioassay (December)		Draft ETL-Field Wetland Animal Bioassay (September)	Draft TR/ETL-Synthesis Report (April)
Effects of Aquatic Disposal on Community Structures				TR/ETL-Effects of Aquatic Disposal on Community Structure (March)
Dredged Material Movement	TR-Documentation and User Guidance for 3-D Dredged Material Transport Model (March)			
Program Synthesis				Draft TR/ETL-Environmental Evaluation of Dredged Material Disposal Alternatives (September)
Field Verification Program (General) 1982-86		District Workshops Input to EPA/CE Implementation Manuals for Regulatory Criteria		

(Continued)

TABLE 1 (Concluded)

Work Unit	1983	1984	1985	1986
		Under Section 103 and 404		
		On Selected Studies, Papers will be Submitted to Appropriate Scientific and Technical Journals		
		Input to Dredging Operations and Technical Support (DOTS) Program Information Exchange Bulletin		

STUDIES ON ANALYTICAL METHOD OF ACRYLAMIDE MONOMER AND ACCUMULATION INTO FISH

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ABSTRACT

Acrylamide polymer is widely used as a coagulant for the treatment of industrial wastewater, domestic sewage, sludge, and reclamation and dredging effluent. The polymer includes 0.01% of acrylamide monomer, a well known neurotoxin.

Data concerning the biodegradability and bioaccumulation of acrylamide monomer are scarce, and an analytical method for measuring acrylamide monomer accumulated in fish has not previously been available. The study reported herein investigated the behavior of acrylamide monomer in the environment and a method for analysis of acrylamide in fish is described.

Acrylamide monomer in fish was analyzed as follows. The fish was homogenized, and the pH of the homogenate was adjusted to 1. Potassium bromide and potassium bromate were added to the homogenate, and the homogenate was stored in the refrigerator (5°C) for 30 minutes. After bromination, the remaining bromine was removed by the addition of sodium thiosulfate; the homogenate was then centrifuged. Dibromopropionamide (DBPA) in the supernatant was extracted with ethyl acetate and measured by GC-ECD. The concentration of acrylamide monomer in fish was calculated from the concentration of DBPA.

Acrylamide monomer accumulation in carp from 10 ppm in solution increased rapidly until the 10th day, slowed from the 10th until the 30th, and then increased rapidly again from the 30th day until it reached 7.65 ppm on the 40th day of exposure.

No accumulation of acrylamide monomer in carp from a 20 ppm acrylamide polymer solution was detected during the experimental period. Acrylamide monomer in polymer used for coagulant did not accumulate in the fish.

INTRODUCTION

Recent advances in scientific techniques have resulted in the production of a large number of chemicals useful for improving the quality of human life. However, some of these chemicals have contaminated the environment during manufacture, use, and disposal. These environmental pollutants can cause serious health problems for man. Therefore, it is very important to understand the movement of chemicals in the environment.

In Japan, the Chemical Substances Control Law was established in 1973 and chemicals are regulated as follows. New chemicals having PCB-like properties are controlled in manufacture, use, disposal, etc., as a Special Chemical Substance. On the other hand, those defined as Existing Chemicals are examined for biodegradability, bioaccumulation, and several toxicities.

The Environmental Agency has conducted environmental surveys on chemicals in samples of riverwater, seawater, rainwater, bottom sediments, and fish. About 20,000 chemicals are on the list of Existing Chemical Substances and about 1,000 of these are produced in amounts of more than 1,000 tons per year. It is impossible to examine all Existing Chemicals for biodegradability, bioaccumulability, and toxicity. Therefore, chemicals having properties such as persistance, ready bioaccumulability, and strong toxicity are selected from screening tests as substances to be surveyed in the environment. Many problems remain. It is often the case that only some of the chemicals in environmental samples can be analyzed quantitatively.

Acrylamide polymer is widely used as a coagulant for treatment of industrial wastewater, domestic sewage, sludge, and reclamation and dredging effluent. The toxicity of acrylamide polymer is slight, but the acrylamide monomer contained in the polymer is neurotoxic and readily water soluble. Any use of the acrylamide monomer in the coagulant invites serious health problems for man. Therefore, it is important to understand the effect of acrylamide monomer on the environment. Figure 1 shows the structure of the monomer and the polymer.

The toxicity of acrylamide monomer is well known (1-15). However, few reports exist on the biodegradability and the bioaccumulation of acrylamide monomer, and an analytical method for acrylamide monomer in fish tissue has not previously been reported. In order to clarify the behavior of acrylamide monomer in the environment, the biodegradability, bioaccumulation, and an analytical method for acrylamide monomer in fish were investigated.

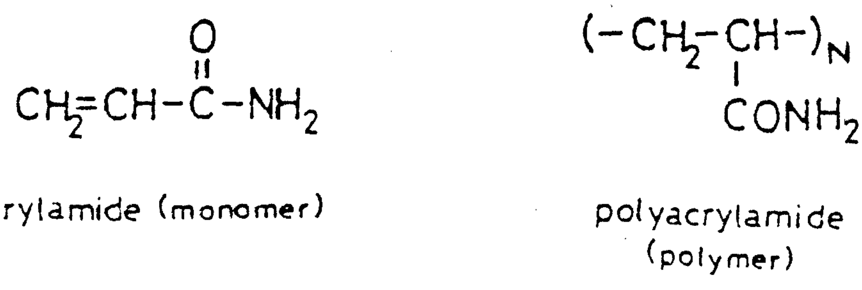


Figure 1. Structure of acrylamide monomer and polymer

ANALYTICAL METHOD FOR ACRYLAMIDE MONOMER IN FISH TISSUE

Several reports discuss the analysis of acrylamide monomer in water. Methods using gas chromatography with flame thermionic detection (16) are not sufficiently sensitive for quantitation of acrylamide monomer at the parts-per-billion level in water. Croll and Simkins (17), Arimitsu (18), and Nakamura (19) reported new analytical methods for acrylamide monomer in water; these are discussed below. The monomer in water was brominated, extracted with organic solvent, and measured by gas chromatograph with electron capture detector. The sensitivity of these methods is sufficient for analysis of water contamination at the parts-per-billion level by acrylamide monomer. However, these methods could not be applied to measurement of acrylamide monomer in fish. In order to investigate the accumulation of acrylamide monomer in fish, an analytical method was developed.

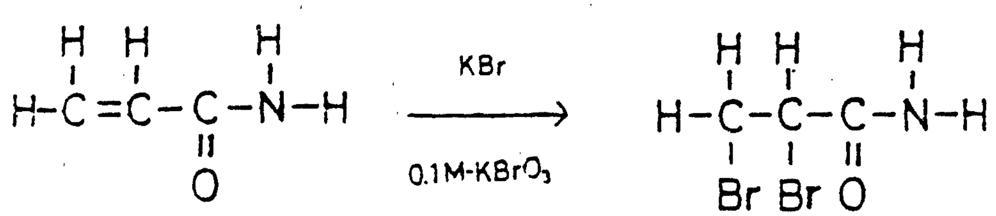
Experimental Method

Packing of the Gas Chromatograph Columns

The suitability of several column packings was evaluated by using an ethyl acetate solution of 2,3-dibromopropionamide (DBPA), which was synthesized from acrylamide by bromination (Figure 2). Column packing materials including Porapak-Q (50-80 mesh), Unipack-1A (60-80 mesh), Amipack 124 (80-100 mesh), Diethylene glycol succinate (25%, support: chromosorb W, 60-80 mesh) (DEGS), Butane 1,4-diol succinate (15%, support: Chromosorb W, 80-100 mesh) (1,4-BDS), Silicone OV 225 (2%, support: Chromosorb W, 80-100 mesh) (OV-225), and Silicone OV-275 (2%, support: Chromosorb W, 80-100 mesh) (OV 275) were packed in 1-m-long glass columns and were tested on the gas chromatograph with electron capture detector (Shimadzu GC-7A). Each test was carried out with the column and detector temperature, rate of carrier gas flow, and range and attenuation of detector set at optimum conditions.

Bromination of Acrylamide Monomer

Fifty micrograms of acrylamide monomer was dissolved in 50 ml of distilled water and the solution was adjusted to pH 1 by the addition of 6 N sulfuric acid. Two, 5, 10, 15, or 20 g of potassium bromide was added to the



acrylamide

2,3-dibromopropionamide (DBPA)

Figure 2. Bromination of acrylamide monomer

solutions and stirred until the potassium bromide dissolved completely; then 10 ml of 0.1 M potassium bromate was added and the solutions were transferred immediately to the refrigerator (5°C) where bromination proceeded for 30 minutes. After bromination, bromine remaining was removed by addition of 1 M sodium thiosulfate solution. The solution was transferred to a separatory funnel containing 50 ml of ethyl acetate and was extracted for 15 minutes. The concentration of DBPA in the ethyl acetate layer was measured by gas chromatograph. From results of the measurement, the recovery of acrylamide was determined, and the optimum quantity of potassium bromide was selected.

The optimum volume of potassium bromate and the optimum time required for complete bromination can also be determined by following the experiment described previously.

Extraction Method From Fish

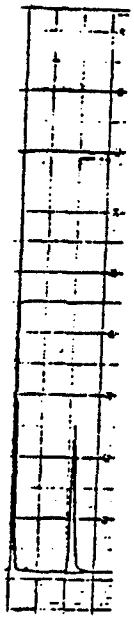
Extraction method a. One milligram of acrylamide monomer was added into 10 grams of fish homogenate, and the volume of the homogenate was adjusted to 50 ml by addition of distilled water. The pH of the homogenate was adjusted to pH 1 by the addition of 6 N sulfuric acid. Fifteen grams of potassium bromide was added to the homogenate and the homogenate was stirred until the potassium bromide dissolved completely; then 10 ml of 0.1 M potassium bromate was added and the homogenate was transferred immediately to the refrigerator (5°C) where it was stored for 30 minutes. After bromination, bromine remaining in the homogenate was removed by the addition of 1 M sodium thiosulfate solution. The homogenate was then centrifuged for 2 minutes at 3000 rpm at 5°C, supernatant was transferred to a separatory funnel, 50 ml of ethyl acetate was added to the supernatant, and the separatory funnel was shaken for 15 minutes. The ethyl acetate layer was then separated from the water layer. The concentration of DBPA in the ethyl acetate layer was measured by gas chromatograph.

Extraction method b. If a peak of DBPA on the gas chromatogram was interrupted by other peaks, the following procedure was followed. The supernatant was transferred to a separatory funnel, 50 ml of benzene was added to the supernatant, and the separatory funnel was shaken for 15 minutes. The benzene layer was then separated from the water layer. The benzene layer was transferred to another separatory funnel, 50 ml of distilled water was added to the benzene layer, and the separatory funnel was shaken for 15 minutes. The water layer was then separated from the benzene layer. The water layer was transferred to another separatory funnel, 50 ml of ethyl acetate was added to the water layer, and the separatory funnel was shaken for 15 minutes. The concentration of DBPA in the ethyl acetate layer was measured by gas chromatograph.

Results

Packing of Gas Chromatograph

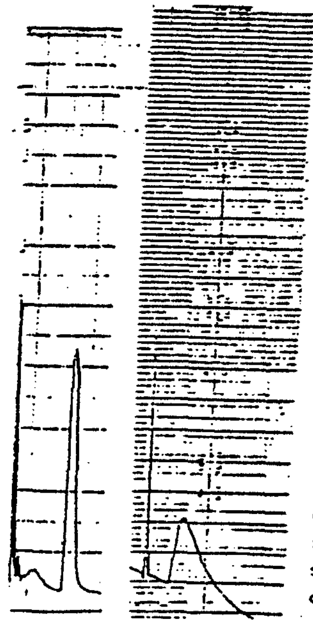
Porapak-Q and Unipak-1A were not usable for quantitation of DBPA. Chromatograms of other packings are shown in Figure 3. In the case of DEGS and 1,4-BDS (Figures 3a and 3b), the DBPA peak was sharp, the separation was good, and the retention time was suitable for quantitative analysis. However, the deterioration of packing activity was rapid and the deterioration was accelerated by using ethyl acetate, and a sharp peak could not be obtained



GC condition

detector	ECD
column	glass column 1m
packing	DEGS
column temp.	175 °C
detector temp.	180 °C
carrier gas	N_2 80 ml/min.
sensitivity	2^4X10
sample size	2μℓ
chart speed	5mm/min.

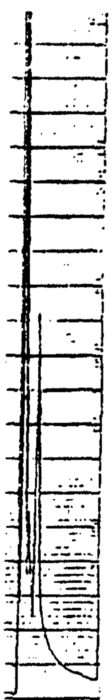
a. DEGS



GC condition

detector	ECD
column	glass column 1m
packing	1,4-BDS
column temp.	170 °C
detector temp.	210 °C
carrier gas	N_2 40 ml/min.
sensitivity	2^4X10
sample size	2μℓ
chart speed	5mm/min.

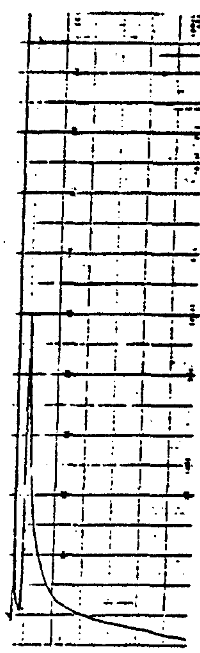
b. 1,4-BDS



GC condition

detector	ECD
column	glass column 1m
packing	Amipack 124
column temp.	110 °C
detector temp.	200°C
carrier gas	N_2 30 ml/min.
sensitivity	2^5X10
sample size	2μℓ
chart speed	5mm/min.

c. Amipack 124

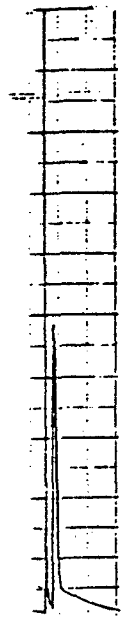


GC condition

detector	ECD
column	glass column 1m
packing	Silicon OV-225
column temp.	180 °C
detector temp.	190 °C
carrier gas	N_2 30 ml/min.
sensitivity	2^4X10
sample size	2μℓ
chart speed	5mm/min.

d. OV-225

Figure 3. Chromatogram of DBPA, 0.1 μg/ml (Continued)



e. OV-275

Figure 3. (Concluded)

after repeated injections. In the case of Amipack 124 (Figure 3c), a DBPA peak as well as other peaks appeared after injection of DBPA ethyl acetate solution and the separation was inferior. In the case of OV-225 (Figure 3d), the retention time was too short and the tailing of the peak was marked and accelerated with repeated injections. In the case of OV-275 (Figure 3e), the peak of DBPA was sharp, the separation was satisfactory, and the retention time was suitable for the quantitative analysis. The peak stayed sharp even after 100 injections.

Bromination of Acrylamide

The relationship between added volume of potassium bromide (KBr) and the recovery of acrylamide (DBPA) is shown in Figure 4. The recovery increased with the increased volume of potassium bromide until 10 grams, then showed a constant value after 10 grams. From the results, the volume of potassium bromide was selected as 15 grams. The relationship between added volume of potassium bromate ($KBrO_3$) solution and the recovery of acrylamide is shown in Figure 5. In spite of the increased volume of potassium bromate solution, the recovery of acrylamide remained almost constant. From the results, the volume of potassium bromate solution was selected as 10 ml.

The relationship between reaction time of bromination and the recovery of acrylamide is shown in Figure 6. The recovery increased with reaction time up to 20 minutes, but remained constant thereafter. Each accuracy of experiment on additional volume of KBr and $KBrO_3$, of experiment on reaction time was less than 1.5% as coefficient of variation respectively. From the results, the reaction time of bromination was selected as 30 minutes.

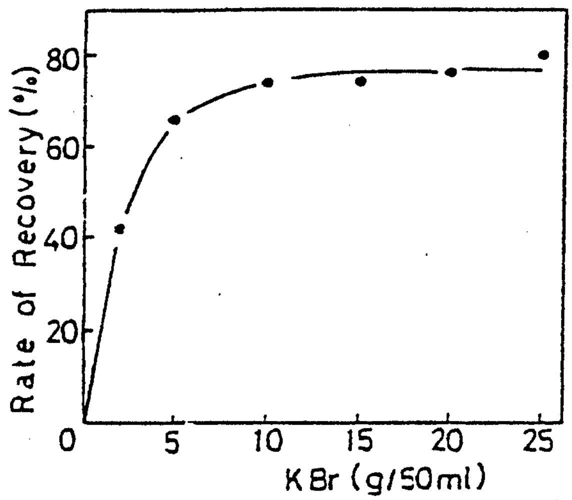


Figure 4. Relation between added KBr and recovery of DBPA

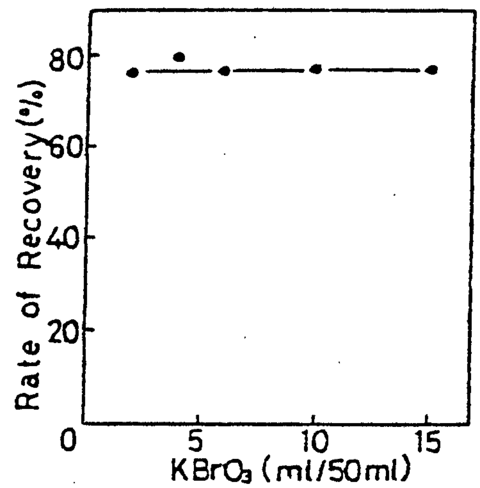


Figure 5. Relation between added $KBrO_3$ and recovery of DBPA

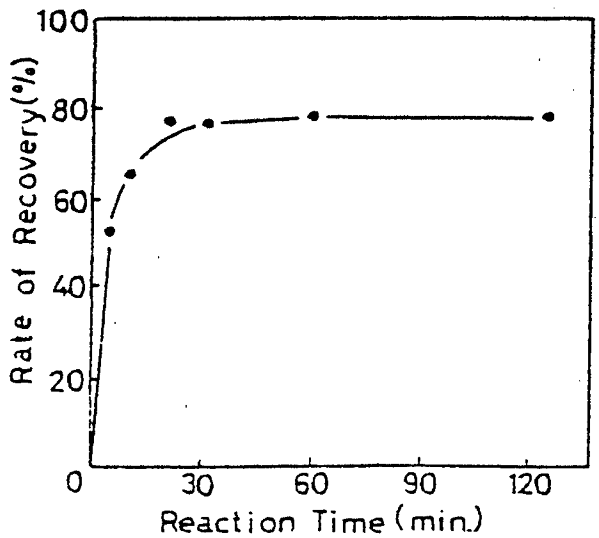


Figure 6. Relation between reaction time and recovery of DBPA

Extraction Method for Fish

The chromatogram of the test solution prepared by extraction method a is shown in Figures 7 and 8. The sharp peak was obtained from the test solution of the experimental group, but the test solution of the control group did not show a corresponding peak. The mean rate of recovery for 20 μg/ml acrylamide added to the fish homogenate was 82.0% and coefficient of variation was 1.72% (Table 1). The test solution of the killifish control group, which was prepared by extraction method a, showed a peak at the same retention time as DBPA (Figure 9). In the case of killifish, the test solution of the control group prepared by extraction method b did not show a corresponding peak at the same retention time as DBPA (Figure 10). The mean rate of recovery of 10 μg/ml acrylamide added to the fish homogenate was 12.06% and coefficient of variation was 7.56% (Table 2).

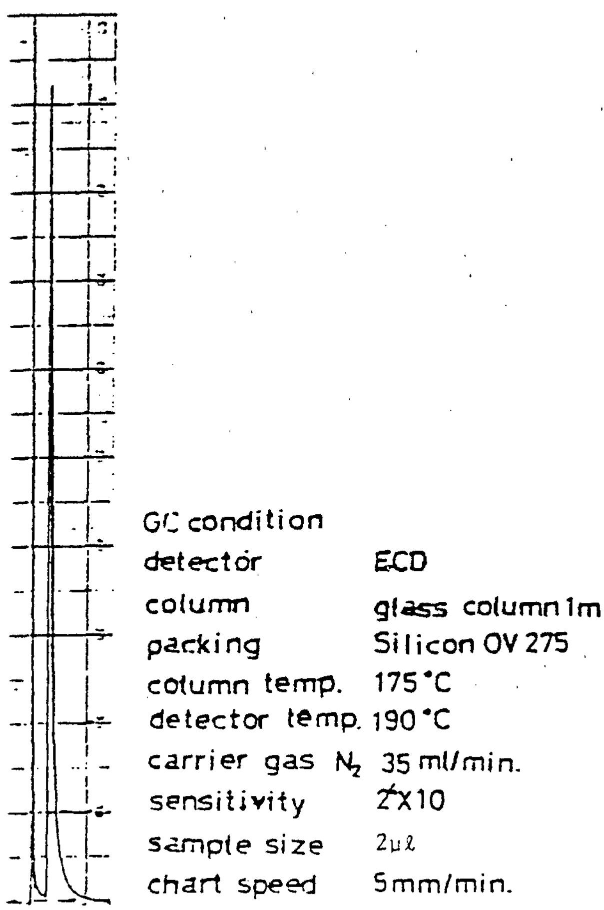


Figure 7. Chromatogram of DBPA, 0.05 μg/ml

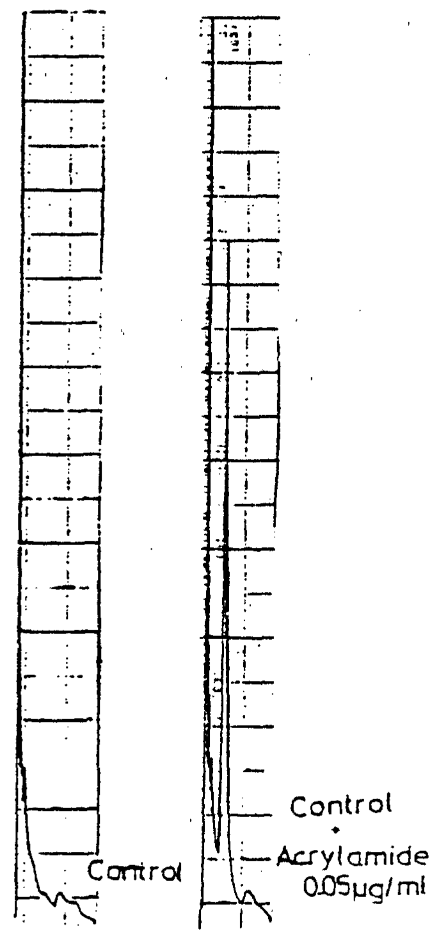


Figure 8. Chromatogram of acrylamide in carp. Extraction: ethyl acetate

Table 1. Rate of recovery of 20 μg/ml acrylamide monomer added to homogenate of fish meat (Extraction: ethyl acetate)

Rate of recovery (%)	83.4
	81.1
	83.4
	80.2
	81.9
Mean	82.0
Standard deviation	1.41
Coefficient of variation	1.72

Table 2. Rate of recovery of 10 μg/ml acrylamide monomer added to homogenate of fish meat (Extraction: benzen-water-ethyl acetate)

Rate of recovery (%)	12.96
	12.13
	12.95
	11.19
	11.07
Mean	12.06
Standard deviation	0.91
Coefficient of variation	7.56

ACCUMULATION OF ACRYLAMIDE IN FISH

Experimental Method

Stability Test of Acrylamide Monomer in Water

It is well known that the acrylamide monomer is unstable, polymerizes readily, and is readily biodegradable. To determine whether or not the concentration of acrylamide in water to be used to raise fish will decrease stability of the acrylamide in water must be tested for 24 hours before start of the experiment.

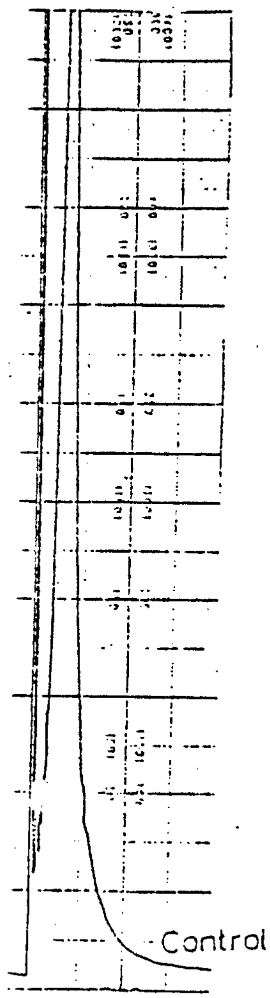


Figure 9. Chromatogram of acrylamide in sea bream. Extraction: ethyl acetate

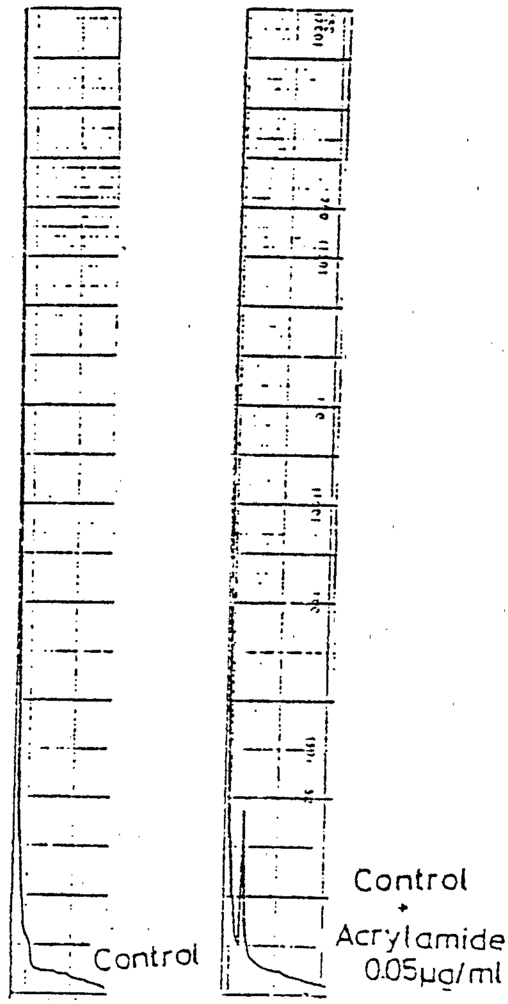


Figure 10. Chromatogram of acrylamide in sea bream. Extraction: benzen-water-ethyl acetate

Accumulation of Acrylamide Monomer in Carp (*Cyprinus carpio*)

Forty liters of distilled water was poured into each of four 40-ℓ fish-rearing tanks (A, B, C, and D). Forty milligrams of acrylamide monomer was added to tank A (1 ppm), and 400 mg of acrylamide monomer was added to tank B (10 ppm). Tanks C and D were used as controls. Forty carp were put into each tank and held for 20 days (tank A) or 40 days (tanks B, C, and D) without feeding. Aeration (600 ml/min) was maintained during the experiment. Rearing water was replaced with fresh water containing acrylamide every day. Water temperature was maintained at 20-22°C during the experiment. Body length and weight of carp were 6.0-20.8 cm and 3.0-35.0 g, respectively. Five to ten fish were removed from tank A at days 1, 5, 10, 15, and 20; tank B at day 1, 10, 20, 30, and 40; and tanks C and D at days 1, 5, 10, 15, 20, 30, and 40. These fish were homogenized and the concentration of acrylamide in the homogenate was measured by analytical method a (described later in this paper).

Accumulation of Acrylamide Monomer in Killifish (*Oryzias latipes*)

Ten liters of artificial seawater was poured into each of three 10-ℓ fish-rearing tanks (E, F, and G). Ten milligrams of acrylamide monomer was added to tank E (1 ppm), and 100 mg of acrylamide monomer was added to tank F (10 ppm). Tank G was used as a control. Five hundred killifish were put into each tank and held for 20 days without feeding. Aeration (600 ml/min) was maintained during the experiment. Rearing water was replaced with fresh water containing acrylamide every day. Water temperature was maintained at 20-22°C during the experiment. Body length and weight of killifish were 2.3-3.3 cm and 0.20-0.25 g, respectively. Sixty killifish were removed from each tank at days 1, 5, 10, 15, and 20. These fish were homogenized and the concentration of acrylamide in the homogenate was measured by analytical method b (also described later in this paper).

Accumulation of Acrylamide Monomer Contained in Polymer in Carp

Forty liters of distilled water was poured into each of four 40-ℓ fish-rearing tanks (H, H', I, and I'). Eight hundred milligrams of acrylamide polymer was added to tanks H and H' (20 ppm); tanks I and I' were used as controls. Forty carp were put into each tank and held for 60 days without feeding. Aeration (600 ml/min) was maintained during the experiment. Rearing water was replaced with fresh water containing acrylamide polymer every day. Water temperature was maintained at 20-22°C during the experiment. Body length and weight of carp were 6.0-21.0 cm and 5.0-40.0 g, respectively. Five fish were removed from each tank at days 1, 10, 20, 30, 40, 50, and 60. These fish were homogenized and the concentration of acrylamide monomer in the homogenate was measured by analytical method a.

Accumulation of Acrylamide Monomer Contained in Polymer in Killifish

Ten liters of artificial seawater was poured into each of two 10-ℓ fish-rearing tanks (J and K). Eight hundred milligrams of acrylamide polymer was added to tank J (20 ppm); tank K was used as a control. Five hundred killifish were put into each tank and held for 60 days without feeding. Aeration (600 ml/min) was maintained during the experiment. Rearing water was replaced

with fresh water containing acrylamide polymer every day. Water temperature was maintained at 20-22°C during the experiment. Body length and weight of killifish were 2.0-3.0 cm and 0.20-0.30 g, respectively. Sixty killifish were removed from each tank at days 1, 10, 20, 30, 40, 50, and 60. These fish were homogenized and the concentration of acrylamide monomer in the homogenate was measured by analytical method b.

Analytical Method a

Acrylamide monomer in carp was analyzed as follows. A 1-2 cm section of the fish was placed in the cup of a homogenizer, an amount of distilled water equivalent to the weight of the fish sample was added, and the mixture was homogenized. The homogenate was weighed and the volume adjusted to 50 ml by the addition of distilled water; pH of the homogenate was adjusted to pH 1 by the addition of 6 N sulfuric acid. Fifteen grams of potassium bromide was added to the homogenate and the homogenate was stirred until the potassium bromide dissolved completely; then 10 ml of 0.1 M potassium bromate was added and the homogenate was transferred to the refrigerator (5°C) immediately and held for 30 minutes. After bromination, bromine remaining in the homogenate was removed by the addition of 1 M sodium thiosulfate solution. The homogenate was then centrifuged for 2 minutes at 3000 rpm and 5°C, supernatant was transferred to a separatory funnel, 50 ml of ethyl acetate was added to the supernatant, and the separatory funnel was shaken for 15 minutes. The ethyl acetate layer was then separated from the water layer. The concentration of DBPA in the ethyl acetate layer was measured by gas chromatograph and the concentration of acrylamide monomer in fish was calculated from the concentration of DBPA.

Analytical Method b

Acrylamide monomer in killifish was analyzed as follows. Killifish were placed in a homogenizer cup, an amount of distilled water equivalent to the weight of the fish was added, and the mixture was homogenized. The homogenate was weighed and the volume adjusted to 50 ml by the addition of distilled water; pH of the homogenate was adjusted to pH 1 by the addition of 6 N sulfuric acid. Fifteen grams of potassium bromide was added and the homogenate was stirred until the potassium bromide dissolved completely; then 10 ml of 0.1 M potassium bromate was added and the homogenate was placed in the refrigerator (5°C) immediately where it was held for 30 minutes. After bromination, the remaining bromine was removed by the addition of 1 M sodium thiosulfate solution. The homogenate was then centrifuged for 2 minutes at 3000 rpm and 5°C, supernatant was transferred to a separatory funnel, 50 ml of benzene was added to the supernatant, and the separatory funnel was shaken for 15 minutes. The benzene layer was then separated from the water layer. The benzene layer was transferred to another separatory funnel, 50 ml of distilled water was added to the benzene layer, and the separatory funnel was shaken for 15 minutes. The water layer was then separated from the benzene layer. The water layer was transferred to another separatory funnel, 50 ml of ethyl acetate was added to the water layer, and the separatory funnel was shaken for 15 minutes. The ethyl acetate layer was then separated from the water layer. The concentration of DBPA in the ethyl acetate layer was measured by gas chromatograph and the concentration of acrylamide monomer in fish was calculated from the concentration of DBPA.

Gas Chromatography Conditions

A gas chromatograph with electron capture detector (Shimadzu GC-7A) and a glass column (length: 1 m, diameter: 3 mm) packed with Silicone OV-275 (2%, support: Chromosorb W. 80-100 mesh) were used. Column and detector temperatures were 175°C and 190°C, respectively. Carrier gas was nitrogen and the rate was 35 ml/min.

RESULTS

Acrylamide monomer in rearing water was stable for 24 hours. The time course of accumulation of acrylamide monomer in carp and killifish from water at various concentrations is shown in Figures 11-16.

The accumulation in carp from water containing 1 ppm acrylamide monomer advanced slowly until day 10 and then increased rapidly until it reached 0.26 ppm on day 20 (Figure 11).

The accumulation in carp from water containing 10 ppm acrylamide monomer increased rapidly until day 10, slowly increased until day 30, and then increased rapidly again until it reached 7.65 ppm on day 40 (Figure 12).

The accumulation in killifish from water containing 1 ppm acrylamide monomer increased slowly until day 10, and then increased rapidly until it reached 0.31 ppm on day 20 (Figure 13).

The accumulation in killifish from water containing 10 ppm acrylamide monomer advanced rapidly until day 15 and then slowly after day 15 until it reached 25.3 ppm on day 20. The accumulation of acrylamide monomer in carp, killifish, and sea bream from water containing 20 ppm acrylamide polymer was nondetectable during this experimental period (Tables 3-5).

DISCUSSION

Environmental pollution by DDT, PCB, methyl mercury, etc., causes serious problems due to strong toxicity of the pollutants and the rapid rate of bioaccumulation. It is important to understand the behavior of chemicals in the environment. In order to clarify the behavior of the acrylamide monomer in the environment, the bioaccumulation of acrylamide monomer in fish was investigated. At the parts per million level, acrylamide monomer in water or alcohol solution can be measured directly using a gas chromatograph with flame thermionic detector (16), but acrylamide at parts per billion level concentrations cannot be detected. To attain the sensitivity required, an analytical method using electron capture detection was developed (17-19). However, problems involving selection of column packings and the technique of bromination had not been resolved and an extraction method for acrylamide in fish did not exist. Because of this, we began a study of the subject and successful results were obtained. The most important problem of gas chromatographic analysis involved selection of the column packing. Selection of column packing affects separation, accuracy, and sensitivity. Nakamura (19) investigated five different packings and reported that ethylene glycol succinate (EGS) had fine sensitivity and resolution. However, the deterioration of packing activity of EGS (and DEGS and 1,4-BDS) was rapid and was accelerated by the injection of

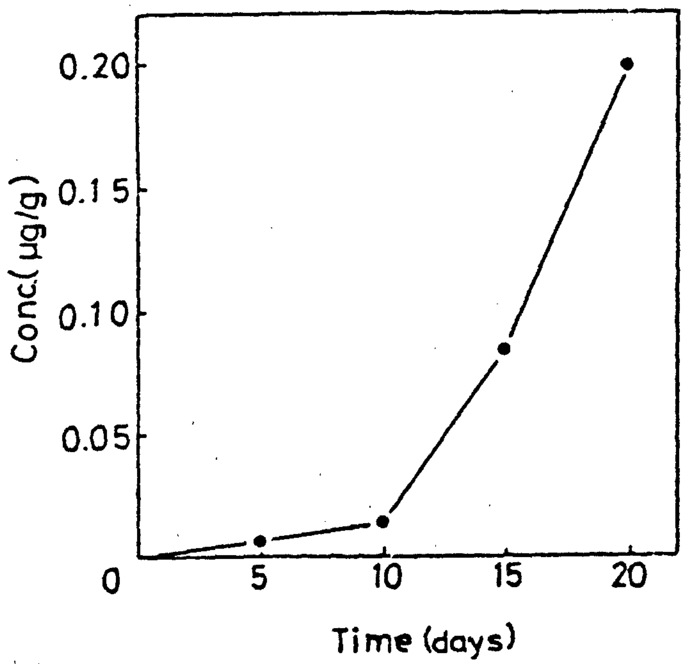


Figure 11. Accumulation of acrylamide in carp, 1 ppm acrylamide monomer solution

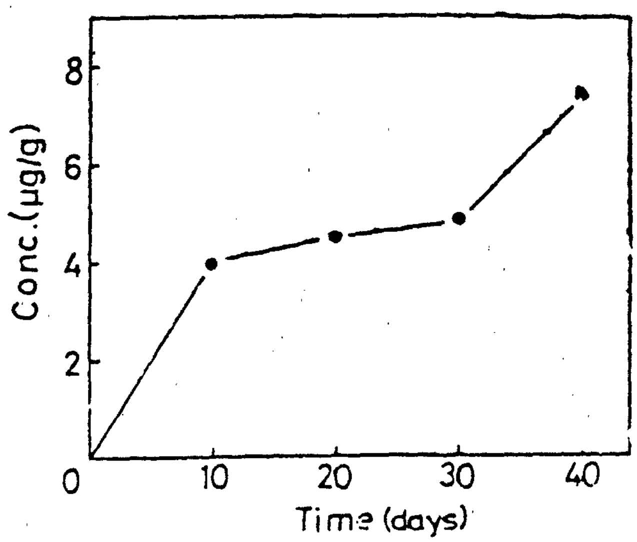


Figure 12. Accumulation of acrylamide in carp, 10 ppm acrylamide monomer solution

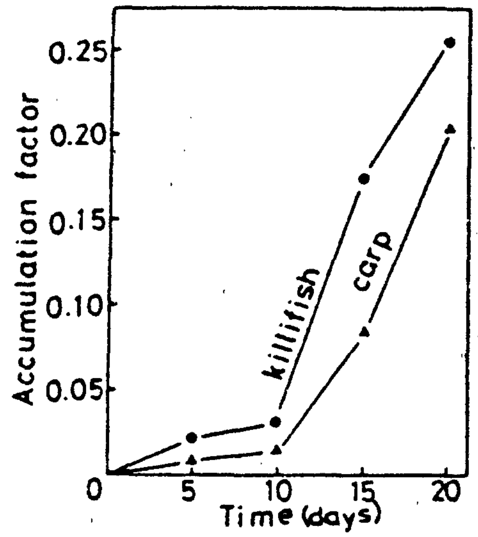


Figure 13. Accumulation of acrylamide in fish, 1 ppm acrylamide monomer solution

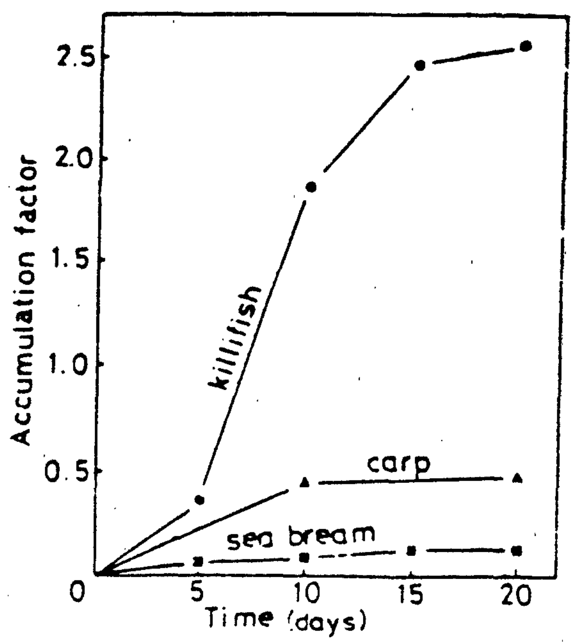


Figure 14. Accumulation of acrylamide in fish, 10 ppm acrylamide monomer solution

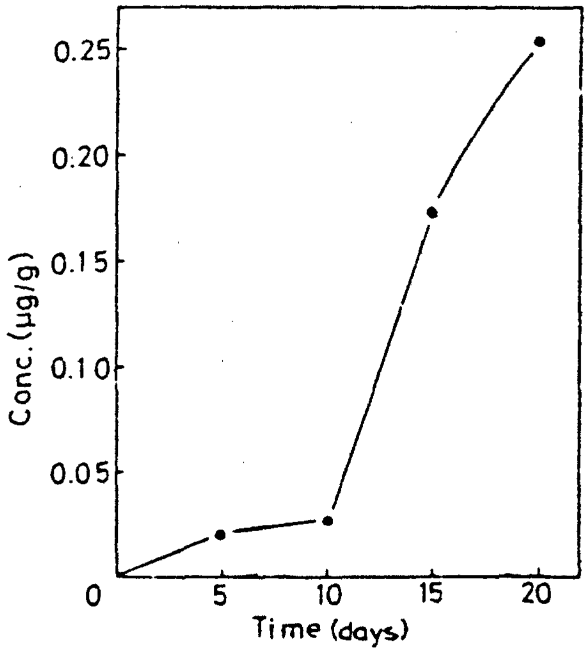


Figure 15. Accumulation of acrylamide in killifish, 1 ppm acrylamide monomer solution

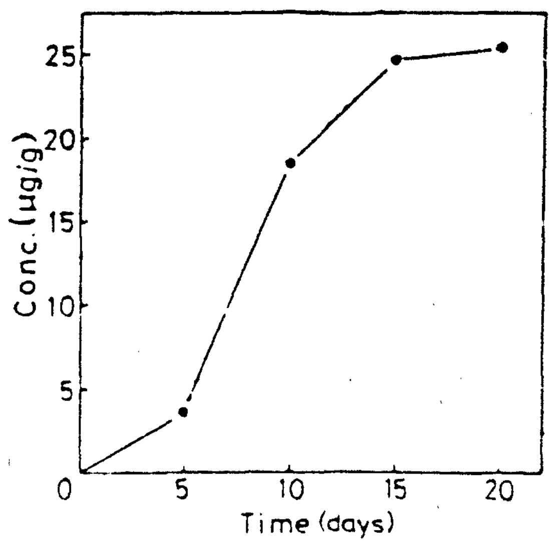


Figure 16. Accumulation of acrylamide in killifish, 10 ppm acrylamide monomer solution

Table 3. Accumulation of acrylamide in carp,
20 ppm acrylamide polymer solution

Time of accumulation, day	0	10	20	30	40	50	60
Concentration of acrylamide monomer, μg/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4. Accumulation of acrylamide in killifish,
20 ppm acrylamide polymer solution

Time of accumulation, day	0	10	20	30	40	50	60
Concentration of acrylamide monomer, μg/g	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Accumulation of acrylamide in sea bream,
20 ppm acrylamide polymer solution

Time of accumulation, day	0	5	10	15	20	25
Concentration of acrylamide monomer, μg/g	0.00	0.00	0.00	0.00	0.00	0.00

ethyl acetate. Using OV-275, the DBPA peak was sharp, separation was satisfactory, and retention time was suitable for quantitative analysis. The OV-275 also had fine sensitivity and superior accuracy. Therefore, OV-275 was considered applicable to the quantitative analysis of acrylamide in fish.

In the bromination procedure, acrylamide reacts with potassium bromide and potassium bromate in the presence of hydrochloric acid. According to Croll and Simkins (17) acrylamide also reacts with bromine under ultra violet irradiation. The recovery after bromination (about 60%) decreased by inhibitors in the reaction mixture. Nakamura (19) reported that acrylamide reacted with potassium bromide and potassium bromate in the presence of sulfuric acid. Recovery by this method was improved and inhibition by anions was reduced.

In this study, procedures for bromination of acrylamide were investigated. In the case of bromination of acrylamide in fish samples, acrylamide must be isolated from organic substances. We obtained successful results by the following procedure. First, the fish homogenate was adjusted to pH 1 by the addition of sulfuric acid; potassium bromide and potassium bromate were added to the homogenate before centrifugation; after bromination, the homogenate was centrifuged and the DBPA was extracted with organic solvent. The recovery of acrylamide from fish by this method was the same as the recovery from water.

The rate of accumulation of acrylamide monomer in fish was far slower than the accumulation of methyl mercury or PCB, in spite of the use of a high concentration of acrylamide such as 1 or 10 ppm in rearing water. In the 1 ppm solution, the accumulation of acrylamide monomer advanced slowly until day 10 and then increased rapidly. It appears that the intake of acrylamide monomer is suppressed in the early days by some action, and then the suppression subsides and the intake increases. In the 10 ppm solution, the accumulation of acrylamide monomer advanced rapidly until day 10 and then slowly from day 10 until day 30. The concentration increased rapidly again from day 30. The suppression in the early days does not show up and the intake of acrylamide monomer increases rapidly, and the more the intake increases, the more the excretion increases, so that the accumulation remains constant.

The accumulation of acrylamide monomer in fish from the polymer was nondetectable. The concentration of acrylamide monomer in polymer is approximately 0.01 and usually 1-10 ppm of polymer is used as a coagulant; therefore, the polymer-associated concentration of acrylamide monomer is approximately 0.1-1 ppb. It may be that at such low concentrations acrylamide monomer is metabolized as rapidly by fish that accumulation does not occur.

CONCLUSIONS

An analytical method for determination of acrylamide monomer in fish was investigated. The rate of accumulation of acrylamide monomer in fish was slow and reached about 0.8 times the concentration in the rearing water (10 ppm) at day [illegible]. The accumulation of acrylamide monomer in fish from polymer was nondetectable. Therefore, it is concluded that the use of acrylamide polymer as a coagulant may not cause serious problems for human health.

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SPECIFICATIONS OF A MODEL OCEAN DISPOSAL SITE FOR DREDGED MATERIAL

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ABSTRACT

When dredged material is disposed at a designated ocean site, it is planned that the bulk of it will remain within the site boundaries for substantial periods of time. But, as is well known, waves and currents of various types are capable of transporting the material for considerable distances, possibly back into the estuary from which it was dredged, unless the site has certain oceanographic specifications. The concept of an ideal site deals with the issue of what size and placement of a site will reduce the possibility of mass transport of sediment without unreasonable increase of disposal costs.

INTRODUCTION

NATURE OF THE PRESENT STUDY

Although in the United States, and elsewhere, the 1970s saw the growth of serious movements to ban the disposal of all wastes into the ocean, I sense that a sentiment is growing today among knowledgeable people that the ocean can be the most appropriate of receiving environments for salt-laden dredged material. In fact, I accept the proposition that even polluted dredged material can be disposed safely into the ocean with minor environmental risk, provided some special care method of disposal, such as clean material capping, is used. Equally important in mitigating environmental impacts is the application of special care in selecting and locating the ocean disposal site. This was not always done in the past, but it is this aspect of the dredged material disposal problem that I wish to discuss here. My principal focus will be upon the oceanographic parameters that must be considered if one hopes to define and situate an ideal or model ocean disposal site for dredged material. Naturally these oceanographic parameters will change from place to place but mainly they will differ only in degree.

Although it is very important to understand what oceanographic parameters must be considered in creating and placing a model disposal site, it is equally important to apply these facts in an orderly way during the process of choosing

the specific location of such a site. Accordingly, as a second major theme, I shall describe a technique for site selection, referred to as the "sieve technique," that I have employed with some success. But prior to expanding upon these two themes of the paper, it will be useful to review the status of existing ocean dredged material disposal sites in U.S. waters. Some of these may fit the template of a model site, whereas others will not.

U.S. POLICY ON OCEAN DISPOSAL

Effective management of any activity or resource must be undergirded by lucid policy. The United States does have a policy governing ocean disposal. It is stated in Sec. 2(b) of the Marine Protection, Research and Sanctuaries Act of 1972, as amended:

> "The Congress declares that it is the policy of the United States to regulate the dumping of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any materials which would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities."

Effective regulation of the disposal of dredged material continues to depend upon the following legal tools provided to the managers of these affairs.

LEGISLATIVE BASIS

Federal legislation controlling waste disposal in the U.S. marine environment appears to have started with the Rivers and Harbors Act of 1899. The impetus for passage of the Act was public dissatisfaction in the 1870s with the heavy pollution of the Hudson River, New York Harbor, and the New York Bight. For a long time pursuant to that enactment, control of disposal of dredged material was vested in the U.S. Army Corps of Engineers and the principal criteria for issuance of disposal permits were concerned with whether or not hazards to navigation or other impediments to transportation would be created. It was not until the decade of the 1970s that truly effective legal tools with which to protect the environment of waterways was provided by Congress.

In 1970, again stimulated by concerns of scientists over the impacts of disposal of sewage sludge and acid wastes in the New York Bight, the Council on Environmental Quality issued a report on ocean disposal that stressed the proposition that regulation should be based to a large extent upon environmental matters.

This report carried recommendations that were incorporated into the Marine Protection, Research and Sanctuaries Act of 1972 (MPRSA) that regulates the disposal of wastes into ocean waters.

Sec. 102 of MPRSA authorizes the Environmental Protection Agency to issue permits for the transportation and dumping of wastes, except dredged and fill material, and to establish criteria for reviewing and evaluating such permits and designating sites and times for dumping. Sec. 103 of the Act authorizes

the Corps of Engineers to issue permits for the transportation of dredged material for ocean dumping in accordance with criteria established by EPA, as noted above.

The international aspect of the regulation of ocean dumping was not long in coming. The International Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (The London Dumping Convention or LDC) was developed in the intergovernmental conference held at London in the fall of 1972. LDC entered into force during August 1975 when the minimum of 15 nations, of which the U.S. was one, had ratified it. I note that Japan became a Contracting Party in 1981, making a present total of 48 signatory nations.

EPA published the Final Ocean Dumping Regulations and Criteria in the Federal Register of January 11, 1977, called for in Sec. 102 of MPRSA. They are still in force although some modifications are under discussion at the present time.

CRITERIA FOR THE SELECTION OF OCEAN DISPOSAL SITES

In the January 11, 1977, document EPA established five general criteria (228.5) and 11 specific criteria (228.6) to be applied in selection and designation of ocean disposal sites. I shall not itemize them here but they will be heeded and mentioned when appropriate as attempts are made to construct and locate a model ocean disposal site.

SPECIFICATIONS OF EXISTING U.S. OCEAN DISPOSAL SITES

GEOGRAPHIC DISTRIBUTION

There are some 131 dredged material disposal sites officially recognized by EPA in U.S. ocean waters. Of these 41 are located on the Atlantic Coast; 4 are in the Caribbean off Puerto Rico; 50 are on the coast of the Gulf of Mexico; 31 are on the Pacific Coast; and the rest are in Hawaii, Guam, and American Samoa. The Gulf Coast accounts for about 70% of the total volume of material generated by maintenance dredging in the U.S. and the New Orleans District alone produces nearly half of that.

SIZE DISTRIBUTION

About half of the present dredged material sites are small (0.5 or less square nautical miles) and an additional 44% are less than 4 square nautical miles (n mi^2) in extent. Only 11 sites (8%) are 4 or more n mi^2. Our model site will have an area of 3 n mi^2, but will be compartmentalized into smaller functional units, as will be discussed later.

DEPTH DISTRIBUTION

Depth is a very important criterion to be applied in placing a dredged material site. Ordinarily, but not always, depth varies directly with distance from shore. About 70% of the existing sites have center depths of 20 m or less. Another 16% have depths between 21 and 99 m, and the remainder (14%) are 100 m or over in depth of which half are in the Pacific where the continental shelf is narrow. Over half of the shallow ones are in the Gulf of Mexico where

the continental shelf is generally very wide. A model ocean disposal site must be sufficiently deep as to preclude the resuspension of fine-grained dredged material by normal winter storm waves. As noted later, an ideal site in the open ocean should be located in water not less than 22 and preferably 25 to 30 meters deep.

DISTANCE FROM SHORE

Distance from shore is certainly an important criterion to be employed in siting both for economic as well as environmental reasons. Economic considerations call for a disposal site to be as near as possible to the channels to be maintained, whereas environmental considerations generally call for greater offshore distances to protect beaches and other amenities. Obviously where channels must be dredged for some distance outward on the shelf, sites may be near the dredger even though they are a considerable distance offshore. About half of the existing sites are in the territorial sea, i.e., 3 n miles or less from shore, while most of the rest are in the contiguous zone 12 or less n miles from shore. Environmentally, depth and size are more important specifications than distance from shore per se.

OCEANOGRAPHIC CRITERIA FOR SIZE, CONFIGURATION, AND LOCATION OF AN IDEAL SITE

DETERMINERS OF AN IDEAL SIZE

In the January 11, 1977, revision of EPA's ocean dumping regulations and criteria we find the following general criterion dealing with dumpsite size, to wit:

> 40 CFR 228.5 (d). The sizes of ocean disposal sites will be limited in order to localize for identification and control any immediate adverse impacts and permit the implementation of effective monitoring and surveillance programs to prevent adverse long-range impacts. The size, configuration, and location of any disposal site will be determined as a part of the disposal site evaluation or designation study. (Underlines added.)

Then in 40 CFR 228.6 (3) we find a specific criterion that relates to size in regard to proposed use of the site, viz., that in selecting a site consideration will be given to:

> Types and quantities of wastes proposed to be disposed of, and proposed methods of release, including methods of packing the waste, if any. (Underline added.)

In selecting the size and configuration of a dredged material disposal site, it is my contention that one must be concerned with:

a) longshore and tidal current speeds and directions,

b) the proposed average annual amount of dredged material to be disposed in the site, and

c) any plans for expansion or deepening of a harbor that would produce extraordinary amounts of dredged material.

In addition to its configuration, the site should, for management purposes, be thought of as subdivided into four sections that would be buoyed from time to time.

SIZE, SHAPE, AND ORIENTATION

The Size of the Site

Study of the volumes of dredged material that Corps of Engineer Districts need to dispose annually into the ocean reveals a range of from a few thousand m^3 up to in excess of about 8 million m^3 in the New York District. I believe that a site having an area of 3 square nautical miles (10.3 km^2) would not only meet the annual needs of all Districts but could accommodate the material to be dredged for channel deepening. A site of this size is somewhat larger than the Mud Dump in the New York Bight (7.71 km^2) which has been in more or less constant use for 60 or more years and had until recently some almost unused portions. Ideally the site would have dimensions of 2.0 x 1.5 n miles (3.7 x 2.8 km), giving a surface area of about 10.3 million m^2 (Figure 1). Accordingly, should the need arise this site could handle in a year as much as 20-30 million m^3 of dredged material without abnormally high initial mounding before compaction.

Shape and Subdivisions

For environmental and management purposes the site should take the form of a parallelogram (Figure 1) with the smaller sides parallel to the course of the longshore currents. This will permit disposing of dredged materials along its long axis without subjecting the same downstream organisms to a constant rain of fine particulates during disposal. The site should be subdivided (figuratively) into four compartments paralleling the ends and each having an area of about 2.6 million m^2. In practice muds (silts and clays) should be disposed in the upcurrent ends of the compartments in order to give maximum extension to the mixing zone.

Location and Orientation

The preferred location and orientation of the site are shown in Figure 1. In the northern hemisphere the Coriolis effect will cause the low-salinity current leaving the estuary (harbor) to turn to the right and move down the coast along with but seaward of the longshore current. At the same time the tidal bottom water will move in from the left; hence, if the site is located as shown with reference to the harbor entrance, there will be less likelihood that dumped materials will be transported back into the estuary, as we shall see wave forces can accomplish.

OCEANOGRAPHIC CRITERIA FOR SIZE AND PLACEMENT OF AN IDEAL SITE

DETERMINERS OF AN IDEAL DEPTH

One of the major concerns in the disposal of dredged material, particularly if it carries some pollutants, is that it should remain in place after reaching the bottom. The two natural factors that can resuspend sediments in

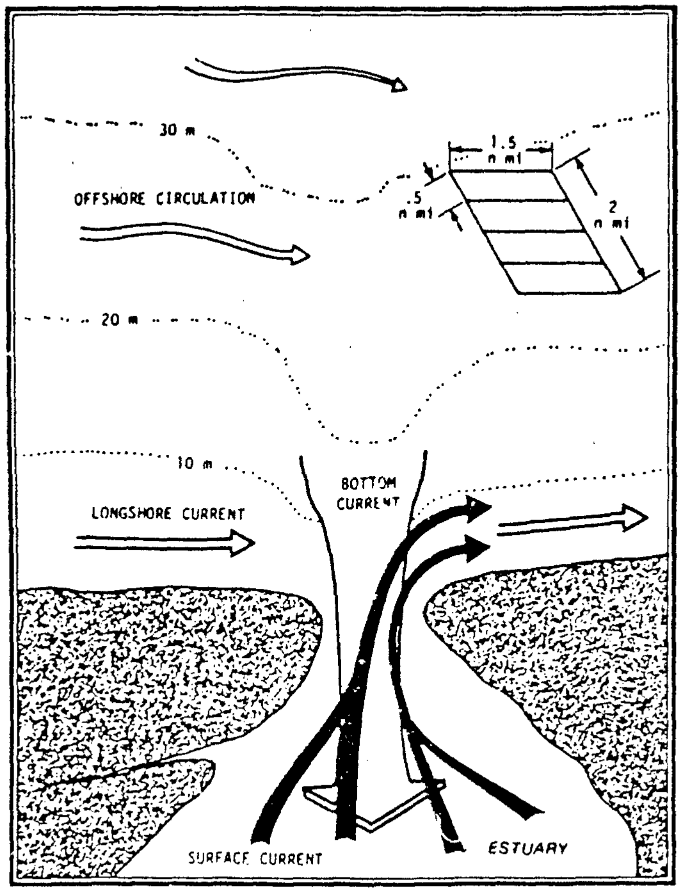

Figure 1. Diagrammatic view showing the entrance to an estuary with its surface and bottom currents and the placement of a dredged material dumpsite in relation to depth, longshore currents, and offshore circulation.

large amounts are waves and currents, both of which are strongly depth related. It is for this reason that depth is considered to be of paramount importance in siting a dredged material site.

WAVES AND THE DEPTH FACTOR

Initial Bottom Disturbance

Certain characteristics of waves must be defined in order to make this section understandable:

a) wave height (h) is the vertical distance from the wave trough to crest. Mean wave heights on U.S. Coasts are ordinarily not over 0.7 to 1.5 m.

b) wave period (p) is the time required for two successive crests to pass a fixed point. Mean wave periods on U.S. Coasts range between 2 and 5 seconds with maxima ranging up to 9 or so seconds.

c) wave length (l) is the horizontal distance from crest to crest.

d) wave velocity (v) is the wave length divided by the wave period.

When waves move into shoaling water their periods remain unchanged but their velocity decreases. Because the period is constant while the velocity (l/p) decreases, it is evident that the wave length decreases in shoaling water. Waves begin to feel or disturb the bottom when the ratio between water depth (d) and wave length (l) d/l is less than 0.5, that is to say when depth has decreased to one-half the length of oncoming waves. For waves of periods of 5 seconds this depth is about 20 m.

The Threshold of Sediment Movement

As the velocity of fluid flow over the seabed increases, a point is reached where the fluid exerts enough shear on the grains to cause them to rise from the bed and move horizontally. This point is known as the threshold of sediment movement (Komar, 1976) (1). The shear stress exerted on the bottom by wave-induced motion stirs up the sediment which may then be moved by a current that by itself would have been incapable of reaching the threshold stress.

TRANSPORT OF SILTS AND CLAYS

Much of the dredged material derived from maintenance dredging is composed of silts and clays; hence, we must consider the conditions under which a disposed mound would be subject to transport by waves or currents or a combination of both. Beds of fine-grained sediments having diameters of 100 µm or less exhibit a high degree of cohesiveness (Figure 2). Thus, flume studies have shown that the threshold shear stress for compact fine silt or clay beds can exceed that necessary to move gravel-sized material having particle diameters of 2.0 mm or more (Drake, 1976) (3). This cohesiveness is produced by unsatisfied particle charges, the strength of which are dependent in part upon water content of the bed, mineral composition, and content of organic matter. There is, of course, an inverse relationship between compaction and water content, with a water content of 80% being of considerable importance (Figure 2). Drake (1976) (3) has concluded that moderately compact mud beds may be eroded at current velocities on the order of 10 to 30 cm/sec (0.2 to 0.58 knots) provided the water content is no less than 80%. That, however, refers to current speeds 1 m above the bottom; considerably lower velocities are required at the water/sediment interface.

The Shoaling Transformation of Wave Structure

An orbital motion of individual water particles occurs in all surface waves. In deep water (d/l > 0.5) these particle orbits are nearly circular with their diameters equaling the wave height at the surface but decreasing exponentially toward the bottom. At intermediate bottom depths, the orbits become elliptical and smaller. When the onrushing waves feel bottom, the elliptical motion decays to a back-and-forth motion of the water with the period of motion equaling that of the surface wave. When this oscillatory movement begins it exerts a shear stress on the bottom and the sediment grains start to feel the waves (Figure 3). This stress is several times larger than the shear exerted by a steady current of equal magnitude.

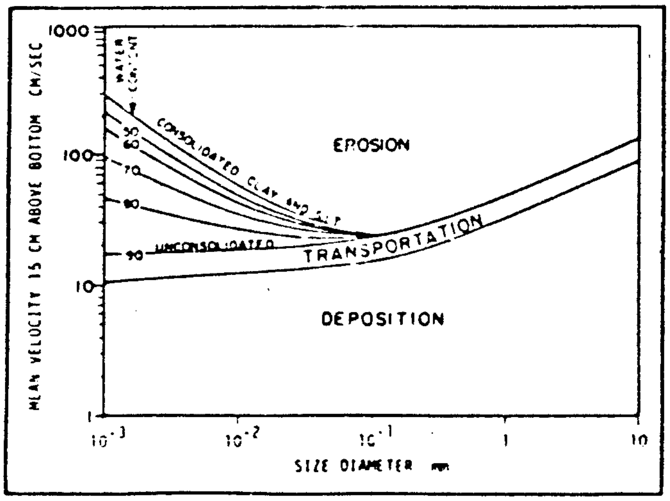

Figure 2. Current velocities required to transport sediments having graded percentages of water. From Postma (1967) (2).

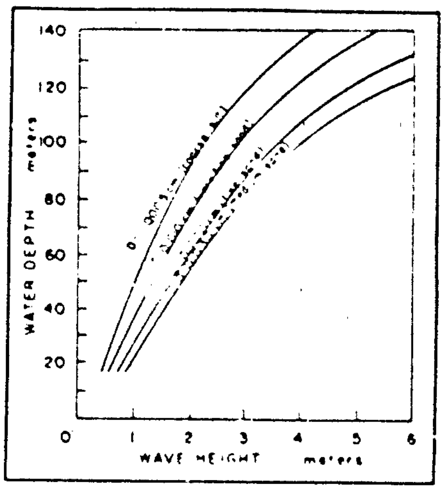

Figure 3. Expected water depth of sediment movement due to surface waves of a 15-second period and a range of sediment grain sizes and wave heights. From Komar and Miller (1975) (4).

There is considerable evidence that at least in shallow water waves alone can produce an onshore sediment transport because of the asymmetry of their orbital motion. As shown in Figure 4, the orbital motion under the crest is of high speed but low duration, whereas the offshore return motion under the trough is of lower speed but longer duration. But even though the surface orbital velocities may be quite high, the velocity decreases very rapidly and becomes very small at depths in excess of 20 m. For instance a wave with a 5-second period and a height of 1 m would have an orbital velocity of 100 cm/sec at the surface but only 1 cm/sec at a depth of 30 m. This orbital velocity will cause fine sands to be transported but not consolidated muds.

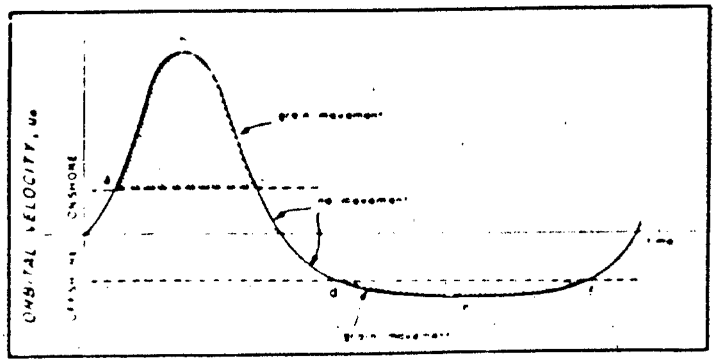

Figure 4. Sediment movement under a near-bottom wave orbital motion, the velocity at b under the crest is higher than at e under the trough. This causes a net onshore movement of certain grain sizes. From Komar (1976) (1).

Some grain sizes especially of quartz sands may be of sufficient size that they are transported only by the stronger onshore orbital motion and are not moved at all by the return offshore flow (Figure 5). A somewhat finer grain size might be moved both during the onshore motion and offshore flow but would only shift offshore a small distance during the return orbit since most of the current of the return orbit would not be sufficient to move the grain. Hence there would be a net shoreward movement. Actually in nature the bigger the particle the more pronounced is the onshore creep (Bagnold, 1940) (5). It is conceivable that with an offshore current superimposed on wave motion, fine sediments that are thrown into suspension will be carried offshore while coarser sediments that remain near the bottom are carried onshore. There are records indicating that on some coasts sands have been transported onshore from as much as 20 km offshore (10.8 n miles).

On the other hand when fine material has been resuspended, even very low velocity currents will tend to carry the material shoreward and if estuaries or harbors are nearby much of the material will be funneled into the estuaries and deposited.

Deposition of silt and some clay will begin at shelf depths where wave surge currents fall below 5 to 10 cm/sec (see Curray, 1960) (6). This depth will depend on the exposure of the coast but generally ranges from 20 to 50 m.

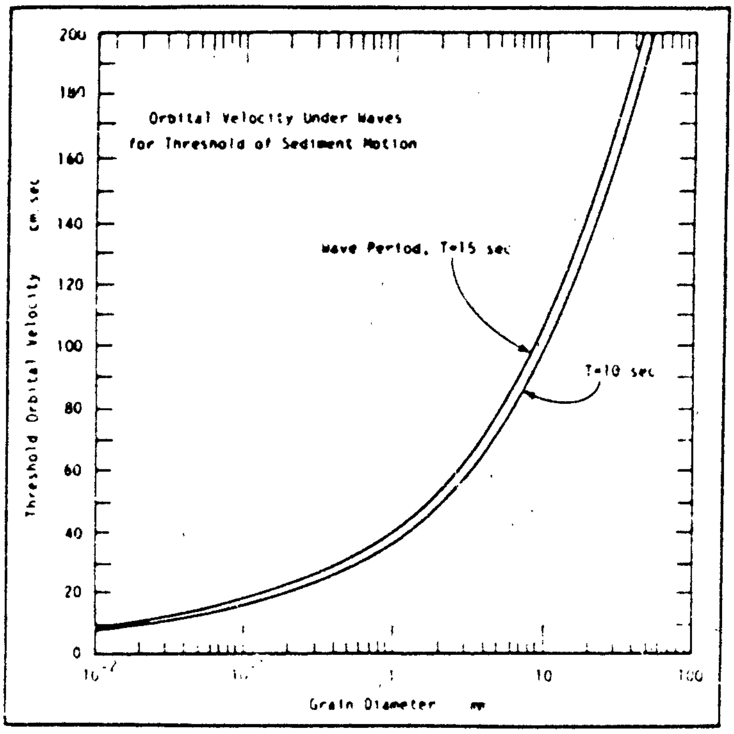

Figure 5. The bottom orbital velocity and wave period (T) necessary for the threshold of sediment motion under waves. From Komar and Miller (1975) (4).

Drake (1976) (3) points out that there are two factors characteristic of fine-grained particulate matter and which tend to greatly increase shelf retention of muds: grain aggregation and interparticle cohesive forces. Shelf suspended sediments, including those derived from dredged material, are always highly aggregated. Aggregates with average diameters in the medium to coarse silt range (31 to 62.5 μm) usually contain hundreds of very fine silt and clay particles bound together by organic matter and van der Waals forces. These aggregates sink much more rapidly than single clay and fine silt particles. The increased settling rate results in a rapid loss of suspended matter from surface waters flowing seaward into near-bottom waters that, in many cases, appear to migrate onshore slowly. Often these particles scavenge pollutants from the water column.

LONGSHORE CURRENTS AND SEDIMENT TRANSPORT

Longshore currents play an important role in transporting sediments that have been brought shoreward by processes mentioned above. If estuaries occur along the coast, some of these sediments will undoubtedly be carried into the estuary. Longshore currents are generated by breaking waves through two processes that in some places occur together. The first of these is the longshore current caused by waves breaking at an angle to the shoreline; the second is the rip current and its associated longshore currents.

Oblique Wave Fronts

In most places waves run up the sloping beach at an angle, but their fall-back is vertical or normal to the beach (Figure 6). As a result, longshore currents are produced which will transport sediments parallel to the coast. Some of these will be beach sands but other components may be material dumped at sea and carried shoreward. For the most part these longshore currents occur inside the breaker zone but under certain conditions they occur seaward of this zone as well.

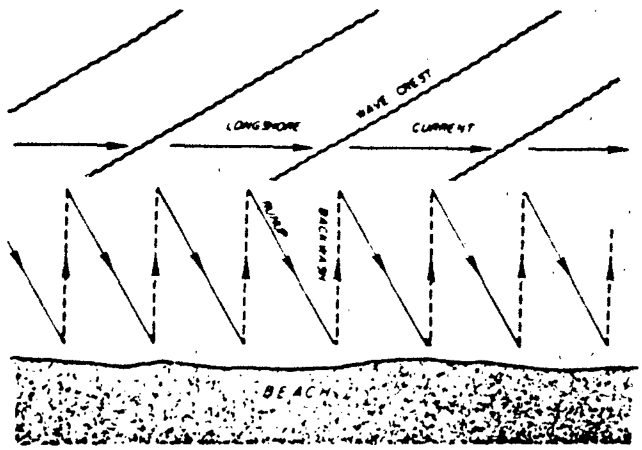

Figure 6. Graphic portrayal of how a wave train approaching the shore at an angle can create a longshore current.

Rip Currents

Rip currents are always associated with longshore currents the cause of which is somewhat more complex than that associated with oblique wave fronts. When waves arrive at the shore with their crests more or less parallel to the shoreline, there is a small lowering of water level just outside the breaker zone while there is a rise of mean water level inside the surf zone. Since it will be higher where the breaking waves are largest, water inside the surf zone will flow along the shore to the areas where the waves are smallest. Thus, the longshore currents converge toward positions of lowest wave breakers where the flow turns seaward as rip currents (Figure 7).

THE SIEVE TECHNIQUE FOR LOCATING AN OCEAN DUMPSITE

DEFINITION

The sieve technique for selecting the location of a dredged material dump-site involves a methodical, step-by-step elimination of unsuitable areas of the seafloor, based on economic, aesthetic, recreational, and environmental criteria, until only acceptable areas for its location remain (see Figure 8). The unsuitable areas for whatever reason will be screened out and darkened on the

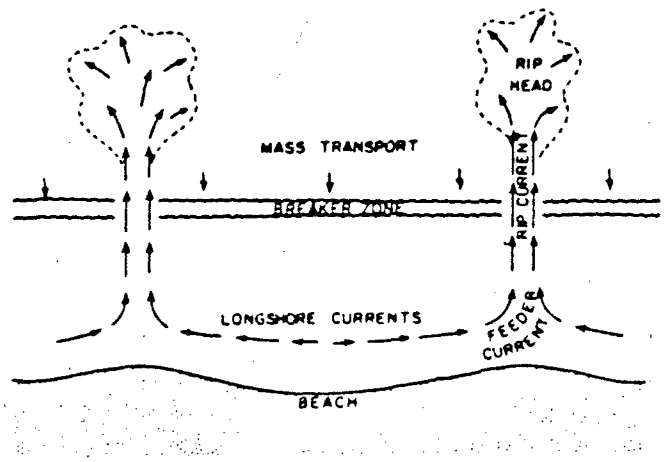

Figure 7. The nearshore cell circulation consisting of (1) feeder longshore currents, (2) rip currents, and (3) a slow mass transport returning water to the surf zone. From Shepard and Inman (1950) (7).

navigation chart. When all such areas have been blocked out, the potential site areas will stand out in bold relief.

CONSTRAINTS IN APPLYING THE TECHNIQUE

It is advisable at the outset to arrive at the maximum haul distance from the harbor entrance that is acceptable for reasons of cost. This distance, however, must be large enough to intersect the 30-meter isobath. Assuming the distance to be 20 km, an arc of this radius is scribed on a navigation chart so that it intersects the isobath at each end. At the same time all shipping fairways should be screened out and darkened (Figure 10). Also, every effort should be made to find an acceptable location to the right of the harbor exit, as noted above.

Assuming a thorough review of the relevant literature and consultations with appropriate public officials and interested environmental and SCUBA diving groups have been completed, and mindful of EPA's specific criteria for site selection, we shall proceed to scribe on the chart (Figure 9) the locations of such features as

a) commercial fishing and shellfishing grounds

b) recreational fishing and diving reefs

c) spawning grounds of important species and their food organisms

d) migration routes of finfish or shellfish including passes into estuaries

e) archeological features

f) beaches and other amenities

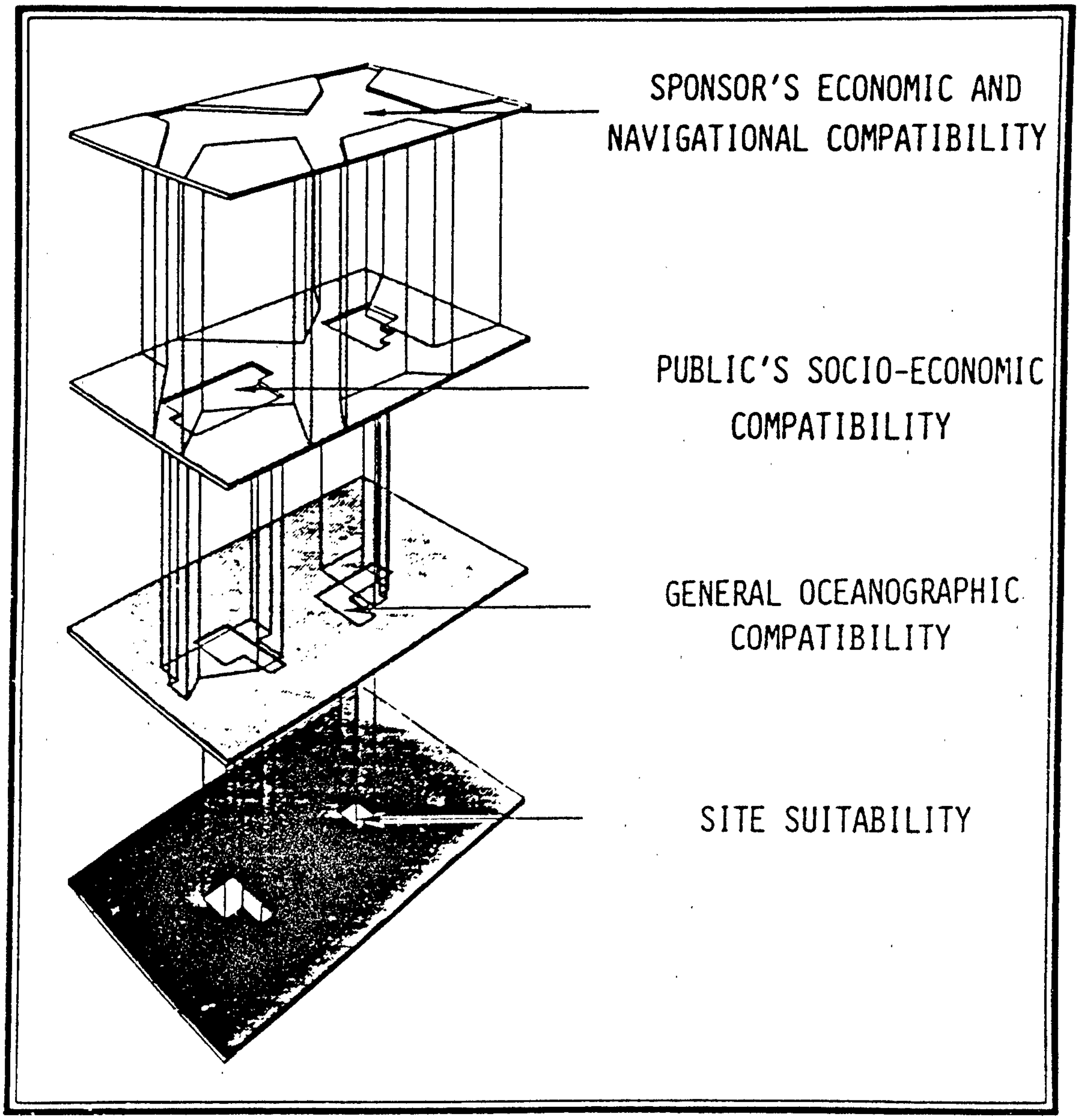

Figure 8. General representation of the sieve technique for siting. Unsuitable areas are eliminated step-by-step until the small white site areas stand out very clearly.

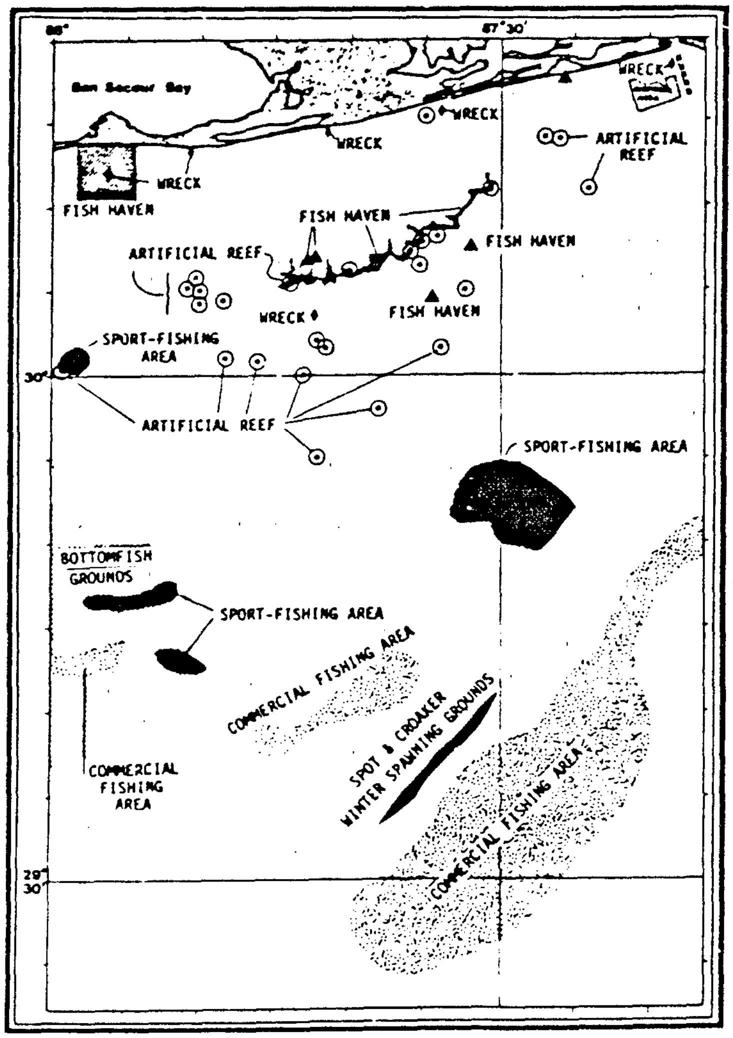

Figure 9. Showing a plot of sensitive environmental areas off Mobile Bay, Alabama, that must be protected by buffer zones and screened out by the sieve technique, as shown in Figure 10.

BUFFER ZONES

Since we can assume that bottom currents may attain speeds up to 0.5 knots and that much of the dredged material except the very finest would settle out in less than four hours, we should protect any amenity and living resource by establishing the adjacent edge of the dumpsite to be no closer than 2 n mi (3.7 km) to the amenity, since this is the distance that a 0.5-kt current would travel in 4 hrs.

Accordingly, these amenities and their buffer zones are then screened out by darkening (Figure 10).

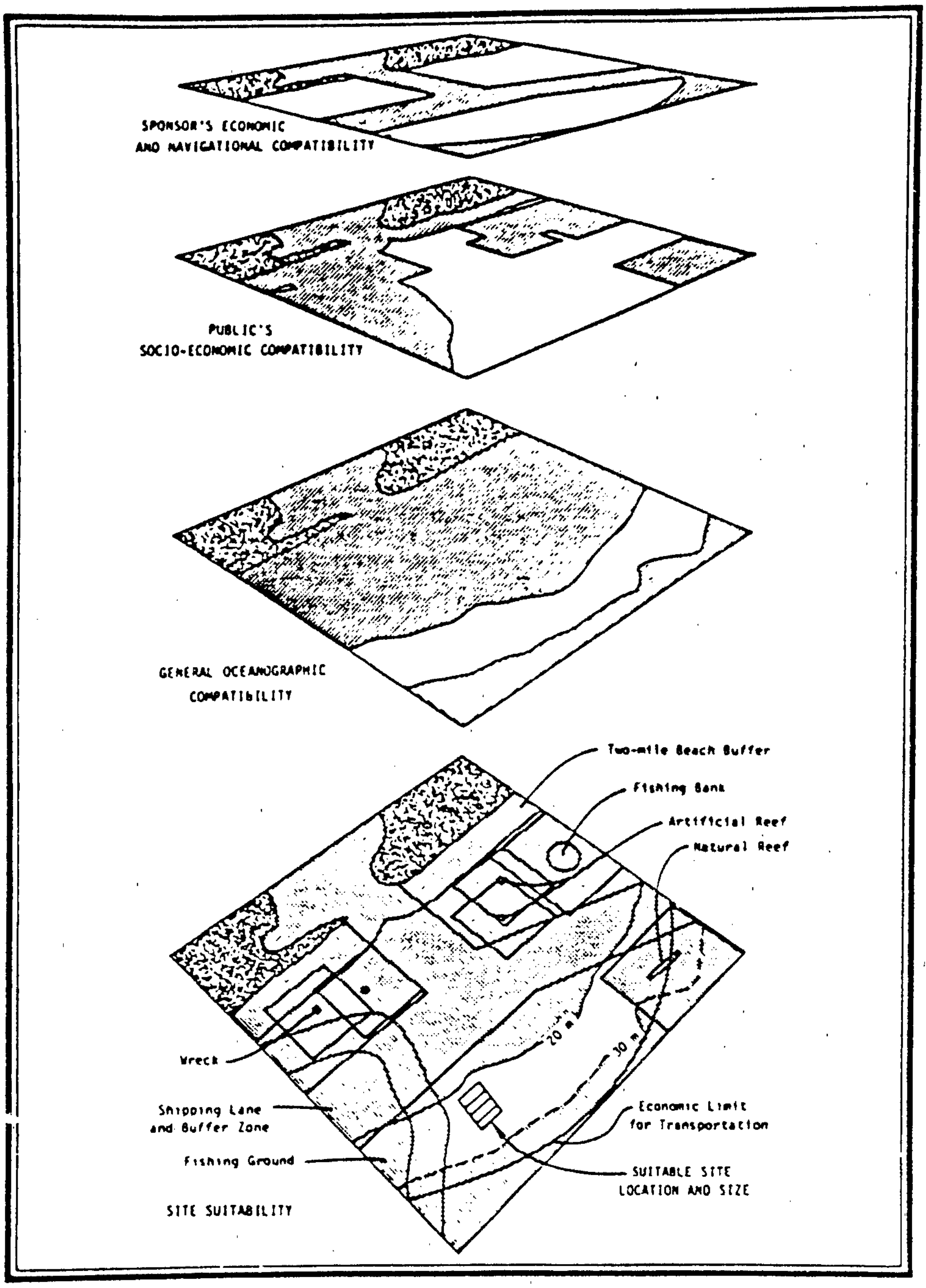

Figure 10. Application of the sieve technique to siting a dredged material dumpsite. Top figure shows the screened out area beyond the haul distance arc and the shipping fairways. The second figure shows areas screened out because of nature preserves and public beaches. The third figure shows depth compatibility. The final figure shows all the screened out areas and the placement of the site.

The unscreened areas that now appear on the chart are suitable for locating the dumpsite. At this point the site will be placed as far down current from the estuary mouth as feasible and then much more detailed parameters such as sediment type can be given consideration in making the final choice.

DEALING WITH EXISTING SITES

Many of the dredged material sites that are in use at the present time in U.S. waters do not meet the above specifications, because they are small and located in very shallow water. This does not mean, however, that all of them should be abandoned. Very likely some of these should be eliminated and a more appropriate site established, but others should be maintained even though they are less than ideal. It is not appropriate here to discuss this topic in detail but guidelines for deciding whether a substandard site should be replaced would certainly include

a) Whether the site is located in an open high-energy environment or in a sheltered part of the coastal environment where normally wave forces are moderate.

b) Whether or not the site receives maintenance dredged material from industrial waterways.

c) Whether the site has received maintenance dredged material during the past five years without observable environmental impact and <u>without public protest</u>.

d) Whether or not there are plans to increase the volumes of material disposed in the site primarily because of new work.

Many more criteria can be brought to bear on this judgmental matter, but in my opinion those sites that satisfy even the above simple guidelines might be given final designation. This would leave time and resources for more careful study of sites that have a history of public concern or that may be scheduled to receive increased volumes of dredged material in the future or that may be considered for disposal of polluted material applying "special care" measures. This issue is obviously worthy of further study.

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SIMULATION OF ESTUARINE SILT TRANSPORT ACCORDING TO STORM WATER RUNOFF

Yoji Baba

INTRODUCTION

Artificially polluted wastewater and solids flow into urban rivers through urbanization and industrial activities. Solids deposit on the estuarine bed due to the reduction of transport ability of the flow.

Deposited solids and silt reduce the effective cross-sectional area of urban rivers which suffer from high runoff rates. At the same time, solids both deposited and suspended sometimes contain chemicals undesirable to the water environment. Their release and suspension damage the river water quality and the aquatic biota environment. Precious water-based amenities and natural property are also damaged.

Fine particles of suspended solids which move in an estuary can form aggregates according to the hydraulic and water quality conditions such as a particle's electrochemical properties and surrounding salinity. High salinity generally produces bigger flocs and aggregates, increases the fall velocity, and accelerates settling to the bed. The movement and deposition of the solids are characterized by channel scales and salinity intrusion of an estuary.

The deposit of silt behaves as a cohesive material and increases its density as consolidation proceeds. Flood flows may form a deposit which contains sand.

Very soft silt, always alternating between suspension and deposition, exists near the bank where the flow is slow and is suspended easily by waves due to navigation and rough weather.

Quantitative analysis of the rate of silt suspension and deposition is useful for planning dredging projects and water quality reservations in an estuary.

This paper deals with a simulation technique of silt transport when a storm runoff event is added to the tidal flow motion. The simulation, fundamentally based on a one-dimensional and one-layer model, is successful to some degree only by changing the fall velocity longitudinally according to the magnitude of measured salinity.

SIMULATION MODEL

This paper shows a simple simulation model of a one-dimensional and one-layer system. Of course, a two-layer model[1] or a two-dimensional model[2] should be used for some salinity circumstances. However, cases where a simple model like this can be applied will exist.

The model used herein is described briefly as follows.

Mass conservation for suspended solids takes an integrated form on the control volume

$$\frac{\partial C}{\partial t} + \frac{\partial}{\partial x}\left(UC - E\,\frac{\partial C}{\partial x}\right) = -\,\frac{B}{A}\left(w_o\bar{C} + \varepsilon_z\,\frac{\partial \bar{C}}{\partial z}\right)_{z_o} \tag{1}$$

where

- C: suspended solids concentration averaged in the cross section,
- $\bar{C}$: suspended solids concentration at elevation z_o (the bed),
- U: cross sectionally averaged flow velocity,
- B: channel width,
- A: cross-sectional area of the channel,
- E: longitudinal dispersion coefficient,
- ε_z: turbulent diffusion coefficient of vertical component,
- t: time,
- x: longitudinal distance,
- z: vertical distance,
- z_o: elevation of the bed, and
- w_o: fall velocity of suspended solids.

Mass balance in the vertical will be rewritten as follows:

$$\left(w_o\bar{C} + \varepsilon_z\,\frac{\partial \bar{C}}{\partial z}\right)_{z_o} = w_o C - \alpha W \tag{2}$$

Where W = erosion velocity of deposited silt layer and α = constant (the rate of erodible particles to the nonerodible). The fall velocity, w_o, depends on many parameters such as specific weight of a particle, particle sizes, particle concentration, and the scale of flocs and aggregates (this also relates to the probability of particle contact and to the magnitude of salinity).

The erosion velocity, W, depends on physicochemical parameters such as material properties of particles, salinity, duration of deposition (density), critical tractive force, and tractive force of the flow.

Many efforts have been conducted to determine quantitatively the magnitude of w_o and W under different hydraulic and water quality environments. Here, they are determined by the experimental facts as follows.

Experiments on depositional behaviors of suspended particles were carried out under freshwater conditions in a circular impeller-driven flume (2847.8 cm long, 30 cm wide, and 29 cm deep).

First, silt is kept suspended in a higher concentration state than the expected equilibrium through a higher tractive force on the silt bed. The tractive force is then reduced suddenly and kept constant for about 24 hours until an equilibrium state of the silt concentration can be reached.

Similar experiments were conducted for both 1 and 3% saltwater conditions. The equilibrium concentrations reached and the shear velocities (u*) applied during the experiments have the relationships shown in Figure 1[3]. The straight lines drawn in Figure 1 show the tendency depending on the salinity. Those straight lines are expressed functionally as fi(u*) (i denotes salinity parameter).

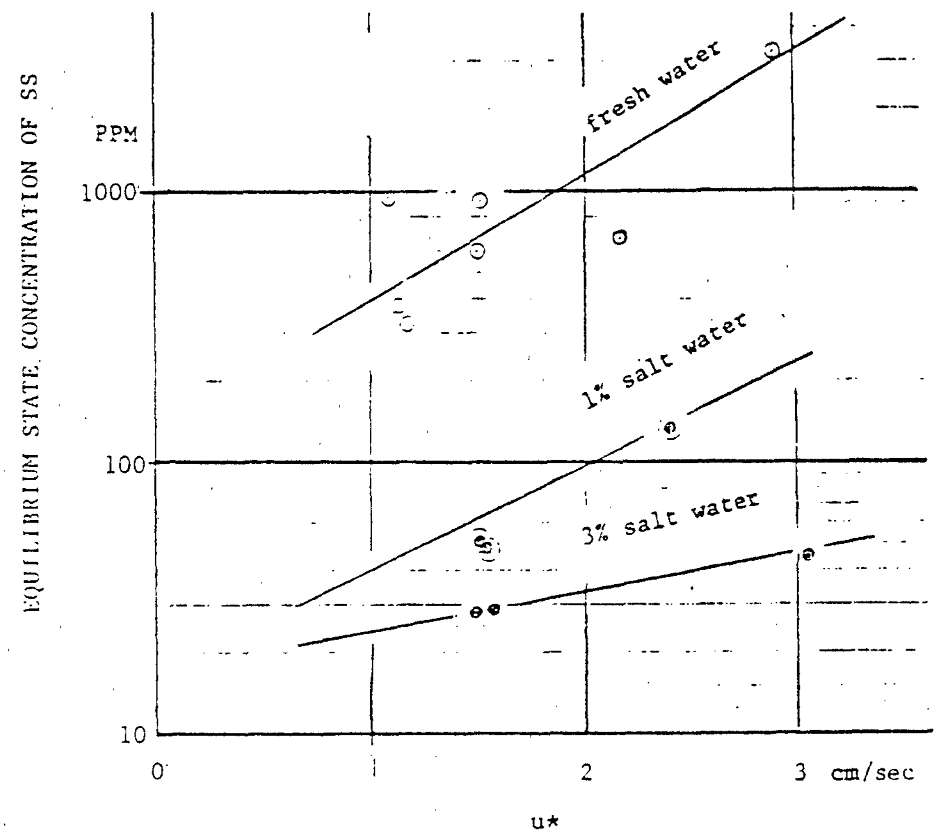

Figure 1. Relationship between SS concentration and shear velocity

At the equilibrium state, from eqs. (1) and (2),

$$-\frac{B}{A}(w_o C - \alpha W) = 0$$

So we obtain,

$$C = \alpha \frac{W}{w_o} \tag{3}$$

On the other hand, from Figure 1,

$$C = fi(u^*) \tag{4}$$

also for equilibrium states. Then we obtain,

$$\frac{W}{w_o} \propto \frac{1}{\alpha} fi(u^*) \tag{5}$$

As far as unsteady flow computations are concerned, Dronker's implicit scheme[4)] is used. For the computation, the discharge is given at 17.2K point (17.2 km) and measured tidal level at 0.0K point for boundary conditions. Time and space intervals for the computation are 60 seconds and 200 to 600 m, respectively.

The boundary conditions for SS (suspended solids) concentration calculations are given at the upper end and Cs of SS concentration in the sea at the lower end (0.0K point) during the rising tide.

A base concentration Co (= constant) is also used, which is almost the same value as the smallest measured, as follows.

$$Cp = C + Co \tag{6}$$

where C is the SS concentration calculation and Cp is the final prediction of SS concentration.

OUTLINE OF THE RIVER OBSERVED

Ayase River was chosen for simulation and field observations. Ayase River runs through the low land area located in the southern part of Saitama prefecture and in the eastern part of Tokyo metropolitan, and finally joins into Naka River approximately 7 km upstream from the sea. The river has a basin area of 165 km^2 and a total length of 49 km. Water pollution has advanced due to the recent radical increase of population.

As water quality preservation measures in the basin, sewage systems are urged to be provided, and dredging and aeration have been in operation. Strict standards for wastewater disposal and total contaminant disposal restrictions are now in effect. A council has also been organized for water quality improvement between responsible authorities and users.

Field observations were made in the 15-km reach (Figure 2) from Kamihirai Gate (0.0K point) to Matsubara Ohashi (15.0K point). Kamihirai Gate is normally opened freely and seawater usually invades through Naka River. The point of Matsubara Ohashi is affected by tidal fluctuations.

The lower half of the observed reach is improved and straightened. The upper half has some bends with relatively great radius of curvature.

Channel width is 25 to 30 m in the lower half and 15 to 22 m in the upper half. Depth of the flow at the average water level is 2 to 2.5 m in the lower reach and 0.6 to 1.6 m in the upper reach.

The thickness of the deposited silt is shown in Figure 3. Though the method to determine the thickness varies from year to year, the big change in the thickness shows the effect of dredging. Generally speaking, both the reaches above 10K and below 3K seem to have tendencies to deposit silt.

FIELD OBSERVATIONS

Observation points were set up, as shown in Table 1, for water level observations and sampling.

Twenty-four-hour continuous observations were made both at spring tide and neap tide. Rainfall and successive runoff occurred during the neap tide observation.

The time interval of observing water level and sampling water was one hour. Water level, water sampling (turbidity, SS concentration, and salinity), surface flow directions, depth of flow, water temperature, and vertical distribution of salinity were observed and recorded. The observations were made in March when water temperature ranged between 8° and 14°C.

SIMULATION OF SS CONCENTRATION AT SPRING TIDE

Figures 4, 5, and 6 show the variation with time of water level, salinity, and computed flow discharges, respectively, during the spring tide observation.

In the computation procedure mentioned above, a constant fall velocity of 0.1 cm/sec (equivalent to the fall velocity of a 33-μ-diameter quartz particle) was used for simplicity.

As for the erosion velocity, W,

$$W = EXP\ (0.71956u^* - 14.5351) \qquad (7)$$

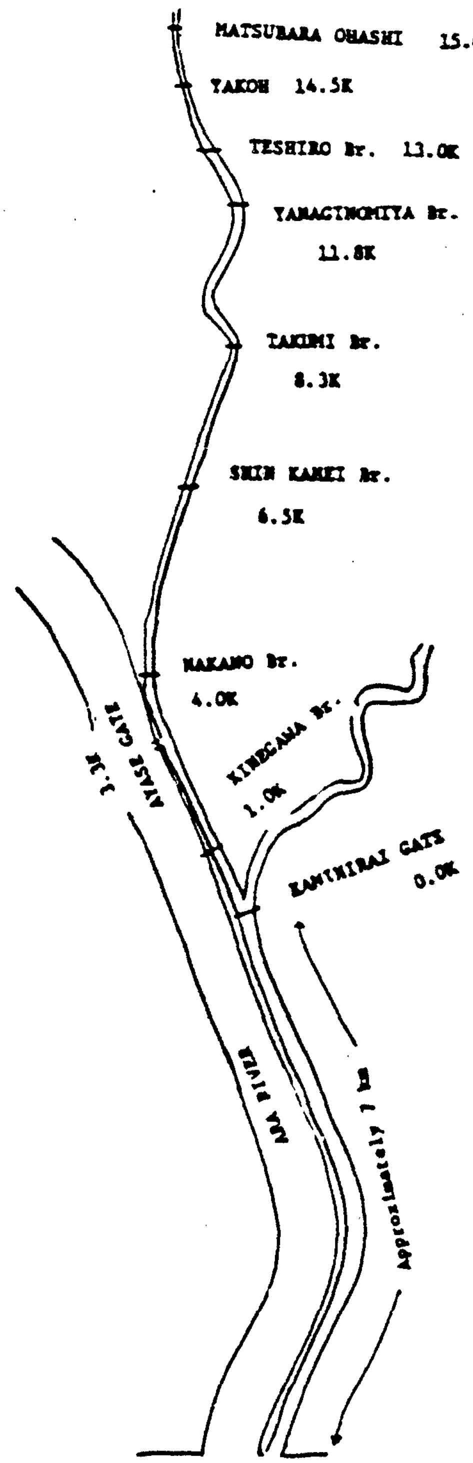

Figure 2. Field observation sites

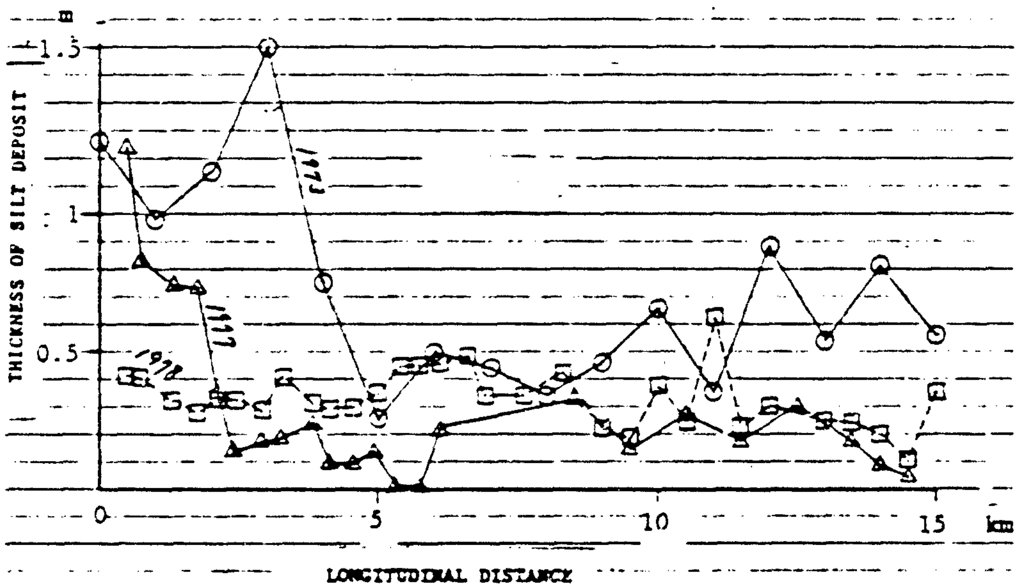

Figure 3. Longitudinal distance

Table 1. Observation Points

Observed Stations	Long. Distance	Water Level	SS Conc. etc.
Kamihirai Gate	0.0 km	°	
Kinegawa Bridge	1.0		°
Nakano Bridge	4.0		°
Shin Kahei Bridge	6.5		°
Takumi Bridge	8.3		°
Yanaginomiya Bridge	11.8	°	°
Teshiro Bridge	13.0	°	°
Yakoh	14.5	°	
Matsubara Ohashi	15.0		°

° Indicates observations were conducted.

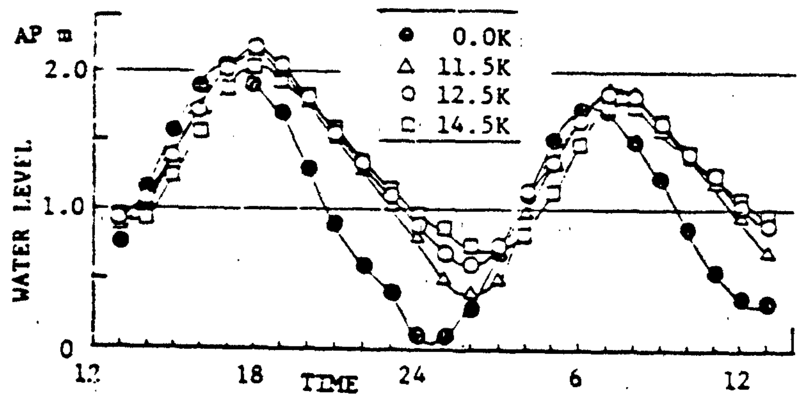

Figure 4. Change of water level

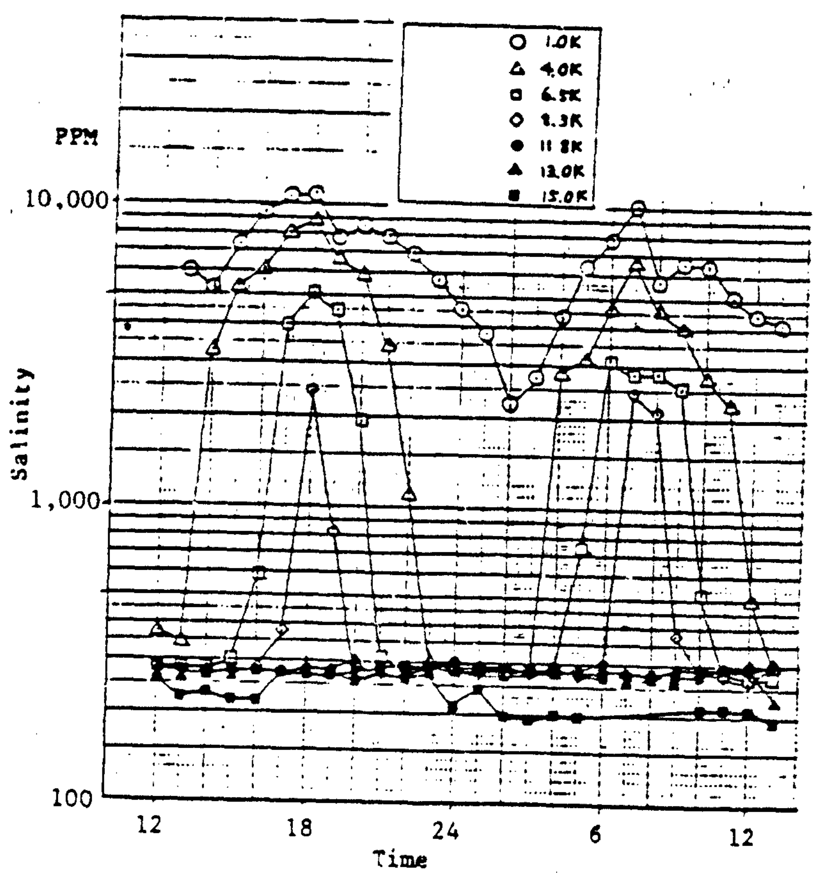

Figure 5. Change of salinity with time

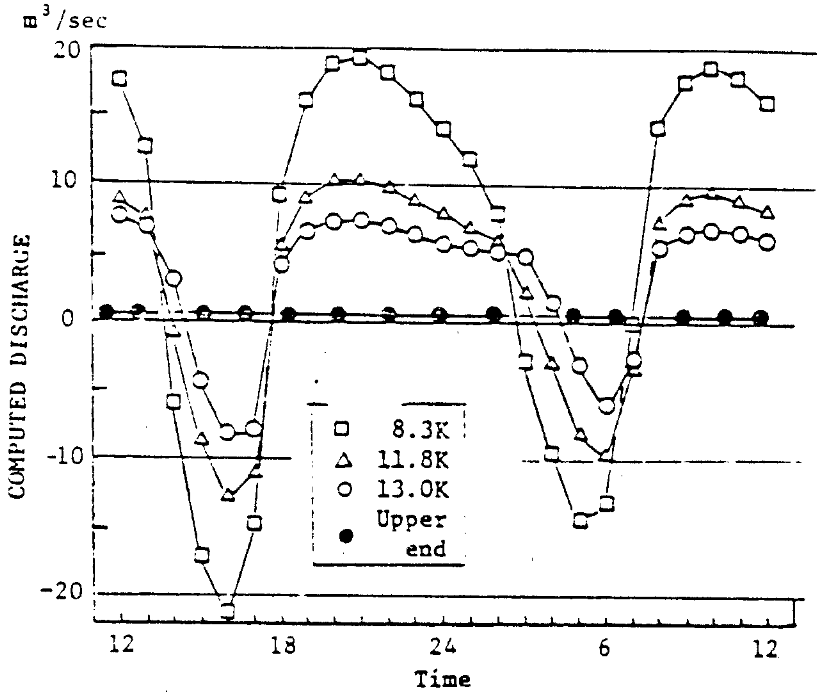

Figure 6. Computed discharge

was used to fit to the observed SS concentrations. Furthermore, the values $\alpha = 0.8$, Co = 12 ppm, and Cs = 0 ppm were used. For the boundary conditions, the discharge at the computing upper end (17.2K) was 0.5 m^3/sec and measured SS concentrations at 15.0K were also used.

Computed results, as shown in Figure 7, considerably agreed well with those measured results.

Computed values both between 2100 and 200 hours and between 1000 and 1200 hours did not agree well. This was caused by the reduction of tidal discharges due to the free outflow from Ayase Gate to Ara River. (The effect is large when the flow of Ayase River is downwards. This model does not consider the outflow and inflow through the gate.)

Though the simulation model is very simple, applicability is not bad. Functional relationships and constants adopted here are almost the same as were used in the simulation of Tama River.

SIMULATION OF SS CONCENTRATION AT NEAP TIDE

Figures 8, 9, and 10 show the variation with time of water level, salinity, and computed flow discharges, respectively, during the neap tide observation. During this observation, 33 mm of total rainfall was recorded. The runoff became remarkable, especially at 400 hours. Computed discharges of the upper end include both those of the upper end and the tributaries.

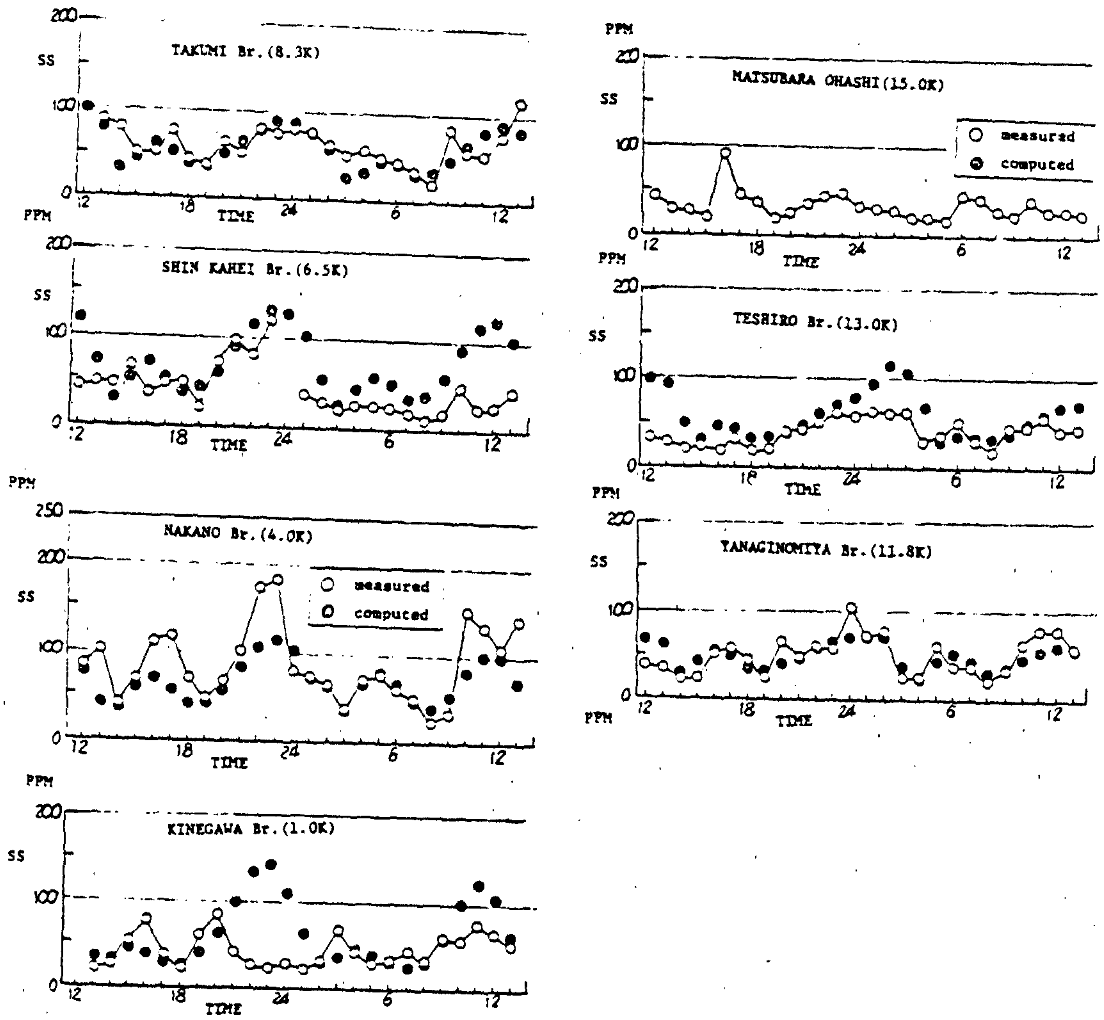

Figure 7. Change of SS with time at various points

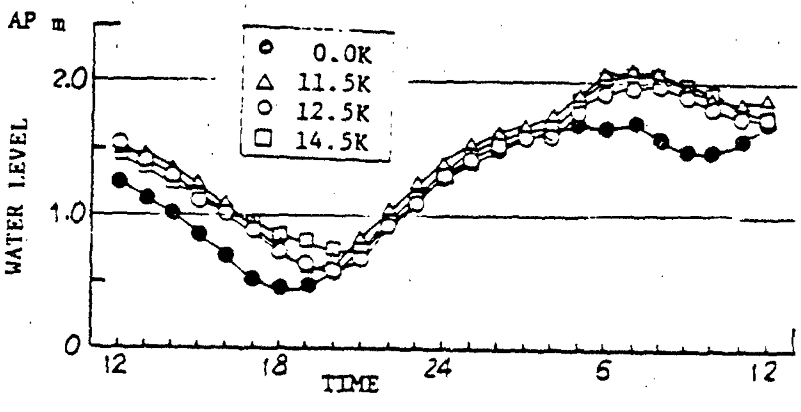

Figure 8. Change of water level

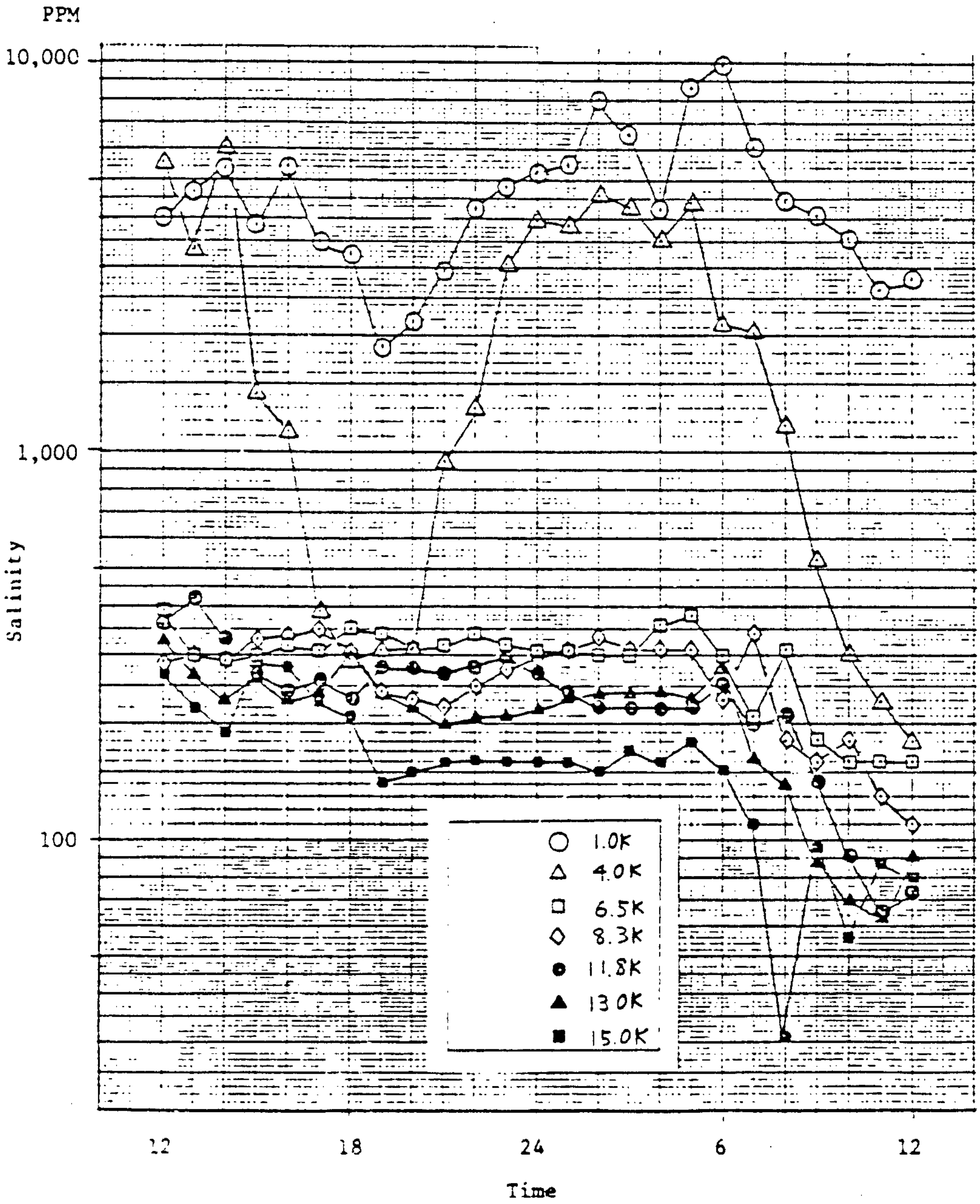

Figure 9. Change of salinity

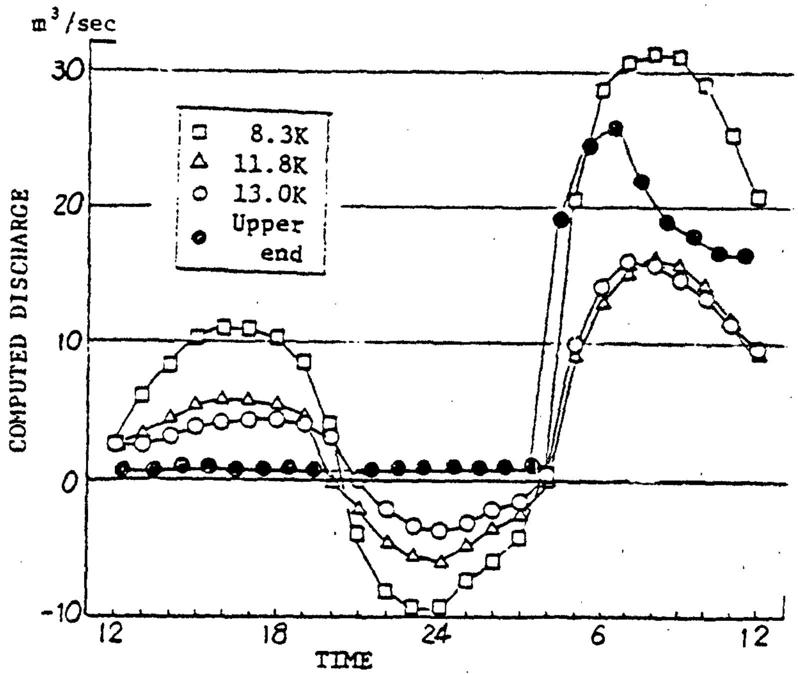

Figure 10. Change of computed discharge.

Figure 9 shows smaller scale changes of salinity than those in the spring tide. Intrusion of saltwater past Shinkahei Bridge cannot be recognized. Storm runoff after 400 hours reduces salinity greatly.

Numerical simulations using the same parameters as those in the spring tide give the results marked by ● in Figure 11. By comparing them with those marked by O (measured), good agreement to some extent is obtained throughout the reach until the storm runoff begins. After runoff begins, agreement is quite poor, especially in the upper reach.

Several improvement techniques can be considered. Figure 11 shows the tendency to agree well if the fall velocity, w_o, is reduced longitudinally after 600 hours. Considering that the variation of w_o is considerably greater than that of W along with salinity variations and that Figure 9 shows the longitudinal and continuous variation of salinity after 600 hours (this means the longitudinal and continuous entrainment of saltwater into runoff water), it seems rational to give a longitudinal change in the value of the fall velocity.

Simulation, giving a stepwise variation of the fall velocity as shown in Figure 12 only after 600 hours, results in the data marked by ▲ in Figure 11.

This small improvement in the simulation resulted in significantly improved accuracy throughout the computed reach.

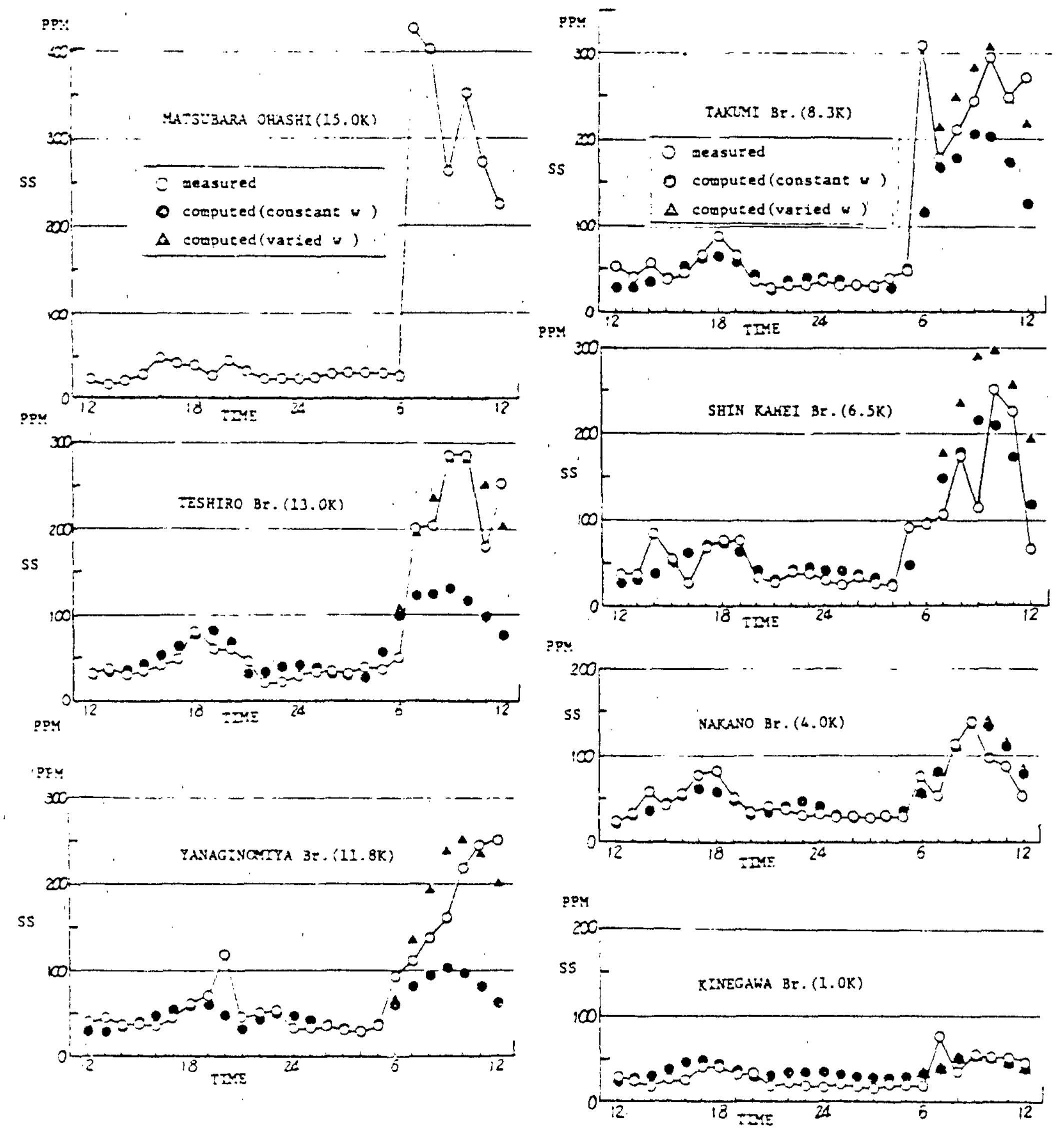

Figure 11. Change of SS

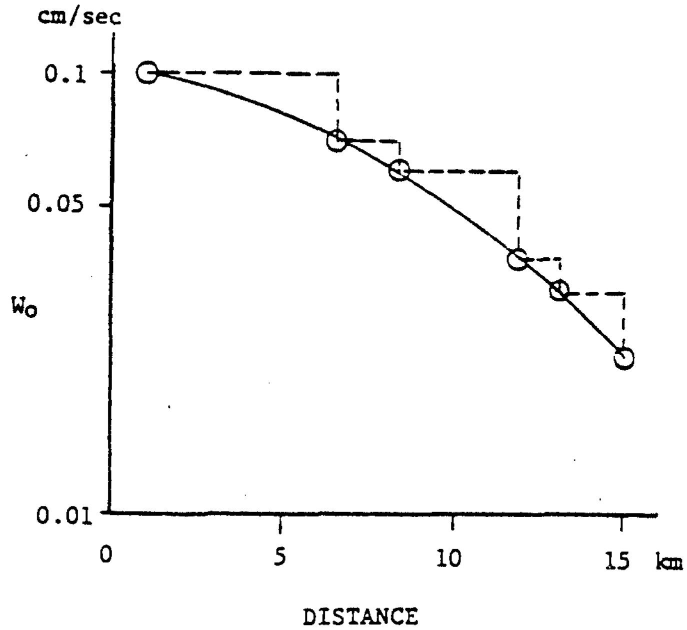

Figure 12. Change of w_o according to reach distance

CHARACTERISTICS OF SS LOAD PASSING THROUGH THE STATIONS

The numerical simulation model presented here can be used with some accuracy for predicting SS concentrations in Ayase River at desired points under several hydraulic conditions with longitudinal movement in suspension and deposition of SS.

Longitudinal characteristics of movement and deposition of SS along the reach concerned are estimated by computing 24-hour load integration at the observed stations both in the spring and neap tide. Figures 13 and 14 show the integrated SS load for a 24-hour period. Figure 13, at the spring tide, demonstrates a go-and-return movement of SS load following the tidal motion, especially at the lower reaches. However, even at these points, net SS load is transmitted downstream.

The quantity of transport is very small at the upper reaches. The integrated volume for 24 hours at each station becomes greater the farther downstream one goes. At spring tide, this means SS load is transported downstream and the erodible river reach incurs a small amount of deposition.

On the other hand, at neap tide, including the storm runoff event, the amount of silt transport is small and a considerable amount of SS load occurs when a rainfall of 35 mm is recorded (SS load transport intensity per unit time is great, especially at upper and middle reaches, and matches the spring tide).

Integrated volumes for 24 hours show the erosion between Yanaginomiya Bridge and Takumi Bridge and deposition between Nakano Bridge and Kinegawa Bridge. The greater amount of deposition downstream of Nakano Bridge includes the loss due to the outflow from the Ayase River to the Ara River.

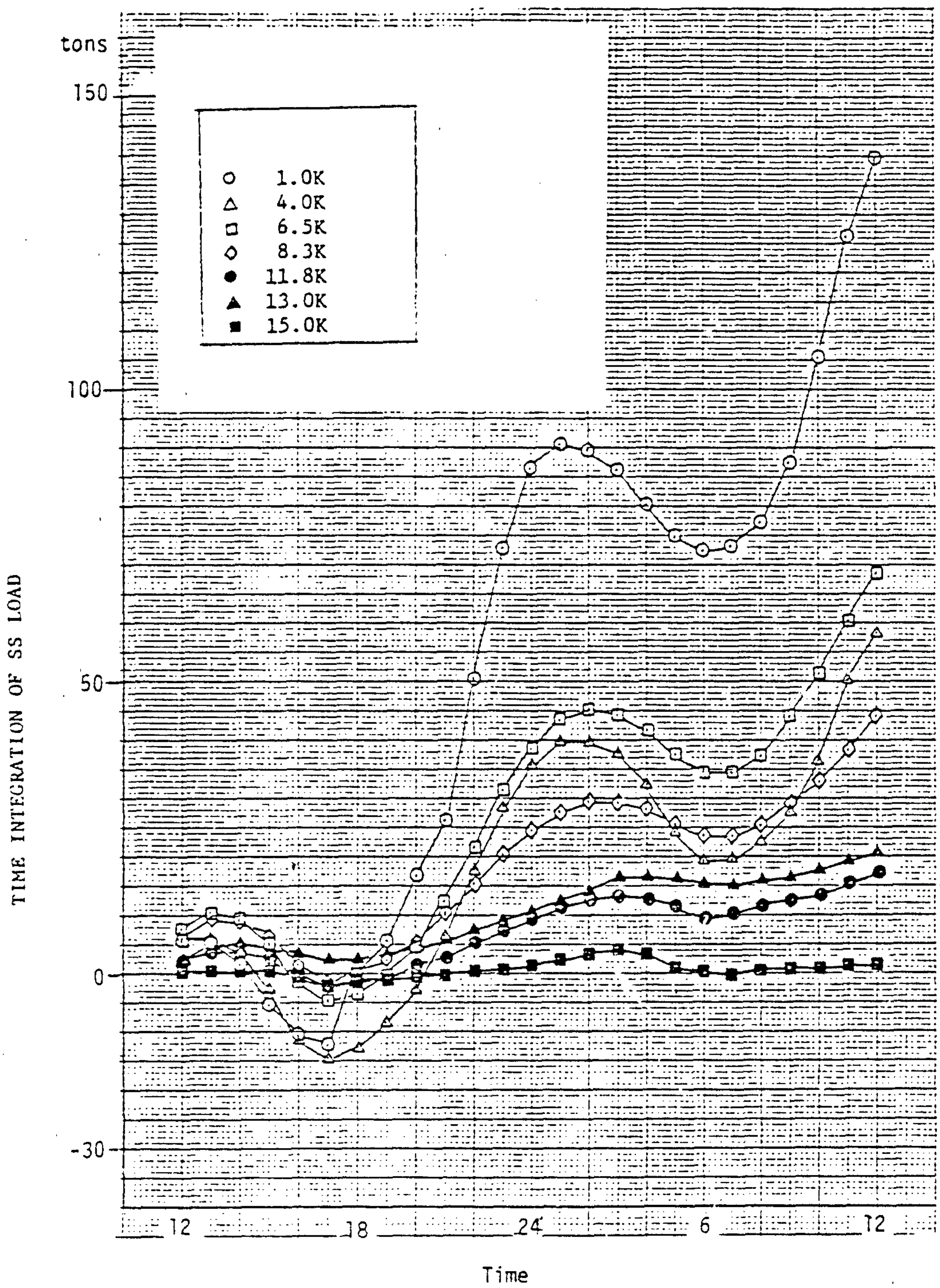

Figure 13. Time integration of SS load, spring tide

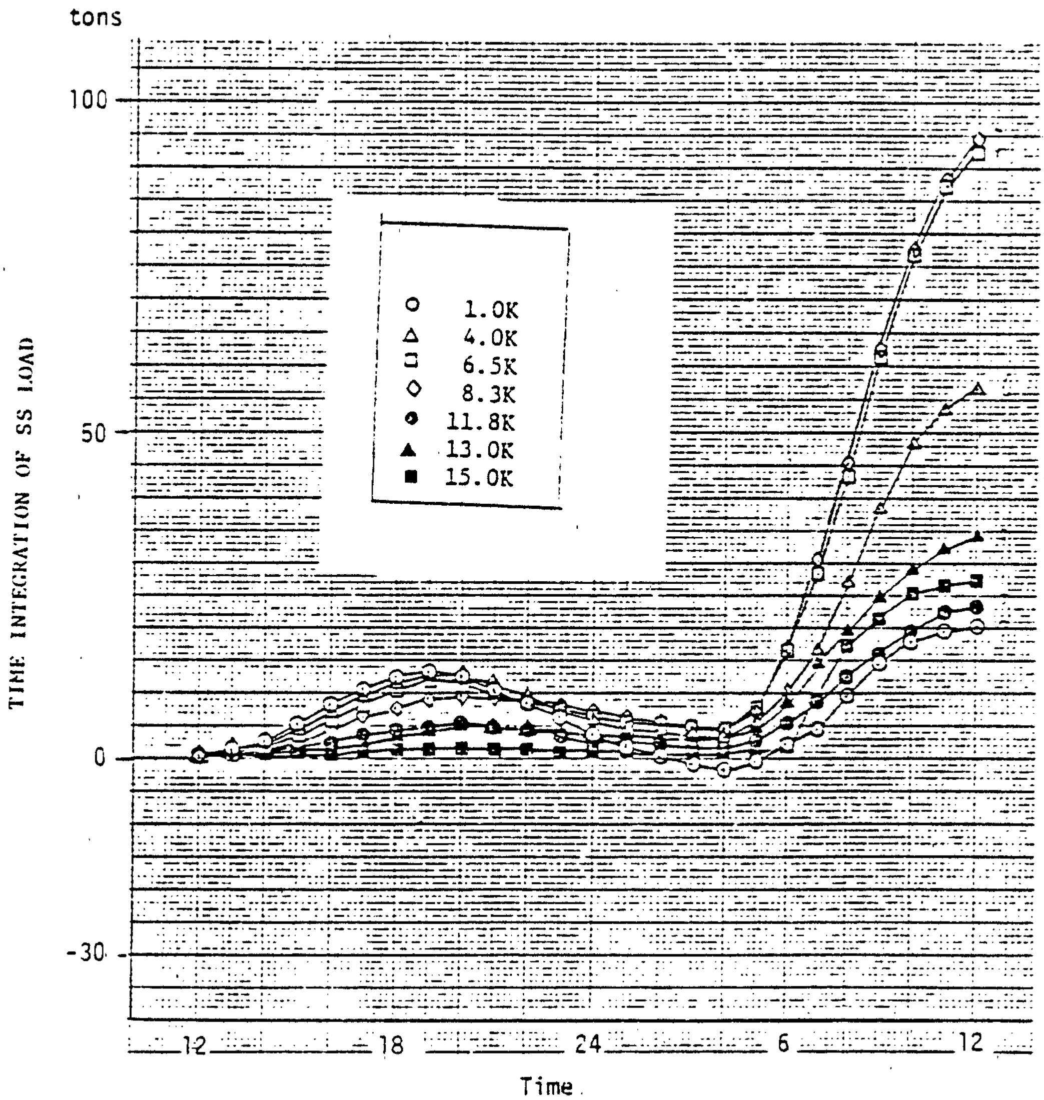

Figure 14. Time integration of SS load, neap tide

In conclusion, the observed reach of Ayase River is expected to have erodible channels during spring tide, small amounts of SS transport during neap tide, and more depositional channels downstream of Nakano Bridge when storm runoff occurs.

It will be possible to predict depositional behaviors (Figure 3) along the observed reach if several observations are made during storm runoff events.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be drawn from this study:

a. Suspended solids transport along the Ayase River reach is numerically simulated using a one-dimensional and one-layer model. The concept of the erosion velocity is used which is determined qualitatively based on experiments.

b. The simulation is satisfactory under the condition of a constant w_o value both at spring and neap tides.

c. In case of a storm runoff, in which the runoff rate is not negligible, longitudinal changes of the w_o value with the salinity level provide a useful tool in obtaining a satisfactory simulation.

d. However, relevant values of w_o with the runoff scale are not now known.

e. Under the hydraulic conditions that cause a definite salt wedge to form, the simulation model cannot be applied.

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RESCUING THE PORTS
AN UPDATE

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ABSTRACT

The environmental movement in the United States of the early and mid-seventies began exacting its toll on the ports of the country in the late seventies. This toll is in the form of time delays in obtaining dredging and dredged material disposal permits, denial of permits, delayed capital investment improvements, increased investment and operation and maintenance costs, and lost revenues. To counter these impacts and to seek state-of-the-art practices in dredging and dredged material disposal activities, both the American Association of Port Authorities and the International Association of Ports and Harbors established ad hoc dredging committees. Since late 1979 these two organizations separately and jointly have pursued similar goals to obtain political recognition and acquire influence to alter United States legislation and international convention. Decisions governing ports and port operations engaged in international trade must be made in the overall public interest and welfare and not excessively hampered by environmental considerations alone. Achieving organizational goals will require continued effort, organizational funding, and exploitation of opportunities to tell the story.

INTRODUCTION

Dredging and disposal of dredged material are essential operations in maintaining the navigability and economic vitality of ports throughout the world. In the United States, more than three hundred and fifty (350) million cubic yards of dredged material per year are dredged from more than 100 ports serving the nation. More often than not, viable disposal options are

limited, and ocean disposal of this material becomes the most economical alternative, least damaging to the environment, and the only practical method of disposal.

One example of the importance of ocean disposal of dredged material to United States ports and the national economy of the country--and one which I am most closely associated with--is the situation in the lower Mississippi River. Here, there has developed a vast deep-draft port complex stretching from Baton Rouge to New Orleans to the Gulf of Mexico--essentially a 234-mile-long port complex that, in 1979, handled 364 million tons of waterborne cargo, foreign and domestic, excluding shallow-draft, through-traffic cargo. The Port of New Orleans, itself, has become the number one port in the United States in total waterborne commerce, foreign and domestic, deep- and shallow-draft, ocean and coastwise commerce tonnage at 177.3 million tons in 1980. According to the Department of Commerce, the Port of New Orleans retained its number one position in foreign waterborne commerce with 58.3 million tons in 1981, while Baton Rouge was listed as fifth in the United States with 30.8 million tons.

Maintaining oceangoing vessel depths at the Mississippi River-Gulf Outlet and the Southwest Passes of the Mississippi River to the Gulf of Mexico has necessitated dredging over the past three years with an annual average disposal of 6.24 million cubic yards of dredged material into ocean waters. Due to location and volume alone, ocean disposal of dredged material is the only feasible method of keeping this vital shipping area open.

DISPOSAL OPERATIONS AND ASSESSING THE ENVIRONMENT

Ocean disposal operations, however, have come under close environmental scrutiny. Many ports throughout the world, and particularly those in the United States, are experiencing increased difficulty in obtaining the necessary government permits to accomplish the dredging required for normal operation and maintenance activities as well as capital improvements. Periodic maintenance dredging is essential for operations at seaports. Delays in performing this maintenance often mean lost revenues, increased shipping costs, and decreased port efficiency. These impacts affect the very economic vitality of a port.

The ports of the United States began feeling the pressures generated by new environmental laws during the early and mid 70's. Mandates of the National Environmental Policy Act of 1969; the Federal Water Pollution Control Act of 1972; the Marine Protection, Research, and Sanctuaries Act of 1972; and other federal laws impacted expansively on the scope and complexity of the federal regulatory program over port and channel construction and operation and maintenance activities. The Administrator of the Environmental Protection Agency (EPA), in conjunction with the Secretary of the Army, was required to develop regulations controlling dredging and filling activities in waters of the United States and adjacent wetlands and controlling disposal of dredged material in ocean waters (ocean dumping). These activities require

evaluation and assessment of probable impacts on the marine environment, wildlife habitats, and, in general, the overall environment of man to include the impact on the well-being of man, himself.

Chemical analyses of materials to be dredged were required after the regulations were promulgated in 1974 and 1975. Soon afterward, water column chemistry was additionally required in the preparation of impact assessments. The degree of testing accuracy was greatly increased when EPA published its "Quality Criteria for Water" in July of 1976. Costs and time required to obtain permit approval were increased considerably.

On January 11, 1977, the United States Environmental Protection Agency revised the "Ocean Dumping" regulations and criteria, requiring additional testing of materials to be dredged. An interim test procedure called "bioassay" was included. Marine organisms such as juvenile shrimps, clams, worms, and fishes are exposed to sediments and water taken from the site to be dredged. Organism survival is evaluated after ninety-six hours. After ten days, the tissues of certain surviving organisms are analyzed for chemical content which would provide an indication of potential for bioaccumulation. On September 7, 1977, the bioassay test procedure became mandatory in evaluating ocean disposal of dredged material.

A Case Study--Port of Lake Charles and Calcasieu River

On November 22, 1977, the U. S. Army Corps of Engineers notified Region VI, U. S. Environmental Protection Agency, of the intent to perform maintenance dredging of the Gulf approach channel to the Calcasieu River and its inland reach.

Considerable discussion developed over the need for bioassays because of exclusions provided for in the regulations. On February 15, 1978, EPA refused approval of the permit until receipt of bioassay results. Bioassays were then run by a contractor, but results indicated a potential for acute toxicity for marine organisms in direct contact with the sediments. The EPA again disapproved the disposal operations, and, thus, the dredging, on July 3, 1978.

The "Ocean Dumping" regulations provide that if the material proposed for dumping does not meet the criteria, the District Engineer may determine that no economically feasible alternative method or site is available and so notifies EPA's Regional Administrator. The District Engineer submitted a report of these findings to the Chief of Engineers on October 11, 1978, and requested that he certify these facts to the Secretary of the Army and request that the Secretary seek a waiver of the criteria from the Administrator. Additional supportive information was provided to the Office of the Chief of Engineers, and the Secretary of the Army subsequently requested the waiver from the Administrator, EPA, on February 7, 1979. Again, additional information was requested by EPA (this was the first waiver request which they had received). On April 18, 1979, EPA granted a partial waiver to Mile 10 for maintenance dredging. Eighteen months elapsed from the time of the original request to granting of the partial waiver--and it was not until

January 7, 1981, that the Administrator of the EPA informed the Secretary of the Army that he granted unconditional approval for the disposal of the maintenance dredging material from the entire requested dredging area into the ocean. In rendering his determination, he found that such dumping would not cause undue degradation to the marine environment. In reaching this decision, a period of over three years had elapsed.

Such delays are costly. But even more staggering is the fact that if this problem had not been resolved and alternative disposal sites had been required, the annual maintenance dredging costs would have escalated from $1.1 million to $62.9 million as measured against an annual project benefit of only $21.0 million. It would have also involved thousands of acres of new dredged material disposal areas.

ORGANIZING FOR SURVIVAL

The American Association of Port Authorities

In response to such ever-increasing problems of delays and escalating costs and to continue efforts of those proposing more stringent, if not always applicable, testing procedures, The American Association of Port Authorities (AAPA) established an Ad Hoc Committee on Dredging in June, 1979. (The Committee is now known as the Special Dredging Committee.) Its establishment was recognition that the then existing AAPA Committee structures and ensuing resolutions were ineffective in moderating the trend toward increasing environmental restrictions on dredging activities. Early on, goals were established. These goals included the identification and documentation of those laws, rules, regulations, agencies, procedures, and agreements which are creating dredging problems. Targeted for study were concerns over mitigation, compensation, endangered species, bioassay test criteria, local costs, permit delays, and interagency agreement. Additionally, the Committee was charged with developing recommended revisions to existing regulations and procedures that would provide needed relief as well as the necessary documentation to support those revisions. Finally, the new Committee was instructed to develop a strategy to be used to achieve adoption and implementation of these revisions and to compile data on key legislators, committees, boards, and administrators to whom these revisions must be officially transmitted.

The International Association of Ports and Harbors

In early 1980, a similar committee to coordinate on the international scene was established by the International Association of Ports and Harbors (IAPH).

At the IAPH Executive Board Meeting in Brisbane, Australia, in April, 1980, there was considerable discussion of the problems that the United States ports had been encountering in their attempts in recent years to dredge their facilities. The Board recognized that those difficulties stemmed in a large measure from the United States being party to the "Convention on the Prevention of Marine Pollution by the Dumping of Wastes and

Other Matter," negotiated in London in November of 1972, and more commonly called the "London Dumping Convention" (LDC). Further, the Board agreed that it would be to the benefit of the IAPH membership to develop a better understanding of port dredging practices and the relationship of those practices to the terms of the London Dumping Convention.

The missions of the International Ad Hoc Dredging Committee are:

1. To review, report, advise, and submit recommendations on major matters relating to seaport and inland port dredging and dredging equipment;

2. To meet with and coordinate with the London Dumping Convention and the Inter-Governmental Maritime Consultative Organization (IMCO), the latter being the organization designated to serve as the Secretariat to the LDC;

3. To develop a program on disposal of dredged material problem areas for inland ports;

4. To publish an inventory of dredging equipment owned by dredging companies worldwide, including a special section on new, innovative equipment;

5. To collect and publish information on the state of the art;

6. To publish an information brochure on sources of information and assistance on dredging techniques and types of equipment best suited for given situations.

WORKING TOWARD THE GOALS

These two committees, the Ad Hoc Dredging Committee of the IAPH and the Special Dredging Committee of the AAPA, have pushed forward in their efforts to resolve regulatory problems confronting the industry and to seek, as well, solutions that are environmentally and economically sound.

On March 14, 1980, AAPA representatives appeared before the House Committee on Merchant Marine and Fisheries to deliver a supporting statement on H. R. 6361, entitled "A Bill to Amend the Marine Protection, Research and Sanctuaries Act of 1972 in Order to Suspend Temporarily the Use of Bioaccumulation and Biomagnification Testings in the Evaluation of Applications Relating to Ocean Dumping of Dredged Material, and for Other Purposes."

> As a result of this hearing, action was taken to develop proposed amendments to the Marine Protection, Research, and Sanctuaries Act of 1972. These amendments, which would resolve many dredging problems, were provided to several U. S. Representatives who promised to co-sponsor the necessary legislation.

Through a meeting on March 19, 1980, the White House authorities of the Carter Administration, the Special Dredging Committee, and the AAPA at large derived substantial benefits and positive direction. The meeting included

AAPA leadership members and was held to provide an opportunity for discussing dredging problems. The group, including myself as the AAPA Special Dredging Task Force Chairman, met with Mr. William G. Simpson, Deputy Assistant to the President; and Mr. David M. Rubenstein, an Assistant to Mr. Stuart E. Eizenstat, Assistant to the President for Domestic Affairs and Policy. Our appeal for support in dredging activities was delivered. We were cautioned that budgets were being cut. Mr. Simpson later advised us that we needed to make stronger and more frequent representations to Congress and involved government agencies.

The members of the AAPA Special Dredging Committee believed that the AAPA could provide influence on ocean dumping controls if AAPA became involved in the United States EPA-chaired Committee on Ocean Dumping, a Subcommittee of the U. S. State Department Shipping Coordinating Committee. This Subcommittee was formed in 1976 to provide an opportunity for public and government interagency comments and advice on United States policy relating to the London Ocean Dumping Convention. As Chairman of AAPA's newly organized Dredging Committee, I requested in June, 1979, that the EPA appoint me as a member of the Committee on Ocean Dumping, also frequently referred to as the "Advisory Committee on Ocean Dumping." The appointment was finalized on August 15, 1979.

Fifth Consultative Meeting, 1980

During 1980, it became apparent that the EPA-chaired Committee on Ocean Dumping was dominated by the outlook of the parent agency (EPA) and sometimes unfounded concerns of environmental organizations and, thus, would not provide the vehicle to influence ocean dumping criteria so as to enhance dredging programs clearly in the national interest. A direct appeal to the London Convention appeared to be the only hope. This was achieved through the cooperation and assistance of Mr. Anthony J. Tozzoli, Port Authority of New York and New Jersey, who is a Vice President of the International Association of Ports and Harbors and, at the time, was also Chairman of that organization's Dredging Committee. Through his good offices, it was possible to arrange for the AAPA Dredging Committee Chairman, who is also a member of the IAPH Dredging Committee, to head an IAPH delegation with observer status at the 1980 Fifth Consultative Meeting of the Contracting Parties to the London Dumping Convention held in London, September 22-25, 1980. This convention is the major global treaty governing the ocean dumping of wastes, including dredged materials. It should be noted that as signatory to this convention, the United States is bound by the adopted international rules and criteria in promulgating national laws and regulations.

In appearing before the London Convention, the IAPH representative presented a position paper directing the attention of the Contracting Parties to possible interpretations of the terms of the LDC and their subsequent application to ocean disposal operations of dredged material. Application of differing interpretation could result in an absolute prohibition of ocean dumping of dredged material--even when there may be no feasible or practical alternative means of disposal, and even when the disposal might be safely carried out if special care is taken. This, it was pointed out, could

threaten world ports with closures resulting in devastating economic impacts upon the flow of international commerce. IAPH urged the Contracting Parties to consider these possible effects upon port operations. The IAPH also proposed a study on the dredged material issue with a view toward adopting whatever changes are needed in the LDC to ensure that there will be no unintended or unnecessary interference with essential port operations.

The concerns expressed by the IAPH delegation at the Fifth Consultative Meeting were well received. The Contracting Parties recognized the significance of the technical issues raised by the IAPH, namely, the use of "special care" in the ocean dumping of dredged material. The consultative parties directed that these issues be considered by the Ad Hoc Scientific Group of the Convention at its next intersessional meeting of May, 1981, and to report to the Convention at the Sixth Consultative Meeting held in London in October, 1981. The Contracting Parties also agreed to consider during the intersessional period administrative/legal issues raised by IAPH as they relate to the application of the Convention and to address such issues at the Sixth Consultative Meeting of the LDC.

IAPH employed a technical consultant in the environmental field, Dr. Willis E. Pequegnat, an oceanographer for Texas A & M University, to develop on a priority basis a technical paper for presentation to the international Ad Hoc Scientific Group. The paper focused upon the "special care" measures raised by the IAPH delegation during the Fifth Consultative Meeting. Dr. Pequegnat advanced the basic premise that ways must be found to permit ports and harbors to continue the dredging of new and existing waterways to ensure the safe passage of commercial shipping. He outlined a number of techniques (clean material capping, borrow pit disposal, split-side disposal, deep ocean disposal, hypersaline basin disposal, submarine canyon disposal, and erection of offshore islands) for the disposal in the marine environment of dredged material containing Annex I substances under the London Dumping Convention.

Ad Hoc Scientific Group Report on Dredged Material (Paraphrased), 1981

As a result of the Ad Hoc Scientific Group's considering the IAPH document at its intersessional meeting in May of 1981 in Halifax, Canada, the Group rendered a report to the Convention.

There was general agreement that, while many of the special measures showed promise for future use, there was very little information on the extent to which the techniques would be successful in practice. The Ad Hoc Scientific Group, therefore, agreed that dredged material (spoil) disposal operations involving special care techniques should be conducted as field research studies to gather experience with a view to allowing "special care" measures to be used on a routine basis.

> The Ad Hoc Scientific Group agreed that existing regulations or the interpretation of the terms "trace contaminants" or "rapidly rendered harmless" in respect to Annex I contamination of dredged spoil could be interpreted to allow national authorities to evaluate research results and utilize, as appropriate,

"special care" measures in the disposal of dredged spoil. These measures should ensure that disposal was conducted in a manner which would avoid undesirable effects, especially the possibility of acute or chronic toxic effects on marine organisms or human health whether or not arising from bioaccumulation in marine organisms, and especially in food species.

The Ad Hoc Scientific Group, therefore, recommended to the Consultative Meeting that Contracting Parties should take note of the possibility of using "special care" methods as suggested by the IAPH where disposal of dredged spoil contaminated by Annex I substances is being considered. The Group also recommended that Contracting Parties should be invited to submit details of any experience gained, with respect to using these methods, to future meetings of the Ad Hoc Scientific Group.

The significance of the issues raised was highlighted not only by the attention that will be given by the Contracting Parties, but also by the inquiry received from Mr. P. A. Haywood, Secretary of the OSLO Commission (which administers the OSLO Convention, governing the ocean dumping of wastes, including dredged material, in the North Sea). Mr. Haywood attended the Fifth Consultative Meeting in London as an observer for the OLSO Commission and expressed great interest in the IAPH position. He requested that the IAPH furnish to him a copy of any statements which had been prepared addressing these concerns, as well as any studies which may be available (or which may be prepared) by the IAPH concerning the ocean dumping of dredged material.

Sixth Consultative Meeting, 1981

Later, at the Sixth Consultative Meeting in London, in October of 1981, IAPH additionally invited the Contracting Parties to express their views upon the applicability of the "emergency" provisions of the Convention to the disposal of dredged material containing Annex I substances which may not be within the "trace contaminant" and "rapidly rendered harmless" exception provisions to Annex I materials. On the issue of "special care" measures, we received support for the Contracting Parties by the acceptance of the recommendations of the Ad Hoc Scientific Group. At the same time, the IAPH confirmed its continuing interest in the consideration of "special care" measures at future meetings of Contracting Parties and the Ad Hoc Scientific Group and extended a continuing offer of technical expertise in matters relating to dredged material. With regard to utilizing the "emergency" provisions of the Convention, the delegates expressed a decided preference of using one of the "special care" techniques proposed by the IAPH rather than consider the matter under the "emergency" clause.

Also, while in London for the Consultative Meeting, members of the IAPH delegation met with members of the International Association of Dredging Companies to initiate a cooperative joint effort. I am pleased to report at this time that the work of both associations has led to developing a draft for a "Dredging Reference Book for Developing Nations." The final proofs will be available for review in December, and we plan to have the book in print in early spring of 1983.

Continued cooperation between the AAPA Special Dredging Committee and the IAPH Ad Hoc Dredging Committee is mutually beneficial and serves to intensify the efforts of both associations. These two committees jointly developed questionnaires for all ports, worldwide. These questionnaires were designed to determine the effect of national and international legal and regulatory controls on dredging efficiency. The final report, "A Survey of World Port Practices in The Ocean Disposal of Dredged Material as Related to The London Dumping Convention," was published in April, 1981.

Section 404/10 Regulatory Relief

Within the United States, experience has shown that an inordinate proportion of delays in granting dredging permits stems from a lack of an urgency, or of a law requiring an urgency, in completing interagency coordination reviews within a reasonable period of time. In this respect, our continuing efforts to cause reforms in the Section 404/10 regulatory programs have been partially successful. In January of 1982, the AAPA wrote to the Vice President of the United States in his capacity as Head of the President's Task Force on Regulatory Relief. In that submission, we emphasized that environmental concerns should not be the overriding public interest factor in issuing or denying a permit, that greater use of general permits should be made in permitting maintenance dredging activities, that interagency coordination provide for greater authority for the Corps of Engineers, and that agency periods for submitting review comments be reduced along with establishing a mandated period of time within which a decision must be made. In May of 1982, the Vice President issued letter instructions to concerned agencies directing administrative reforms along the lines suggested and not consistent with existing laws.

Hearings on the Reauthorization of the Marine Protection, Research and Sanctuaries Act of 1972 (1982)

In June of this year representatives of AAPA again appeared before a subcommittee of the House of Representatives to voice concern in the direction that the Committee appeared to be headed in reauthorizing Title I of the Marine Protection, Research and Sanctuaries Act of 1972. The Senate Environment and Public Works Committee approved a bill earlier this year to be presented to the full Senate that provided for a straight one-year authorization of the Marine Protection, Research and Sanctuaries Act. The version under consideration by the House Subcomittee provided for an amendment that essentially would make the London Dumping Convention a self-executing treaty. Treaties are of two kinds; those that are self-executing and those that require enabling legislation. The London Dumping Convention is not self-

executing. It was drafted in general terms for subsequent implementation by signatory countries according to their national authorities. We strongly opposed any "Convention Adherence" language being inserted as an amendment to the Marine Protection, Research and Sanctuaries Act of 1972. To suggest a separate application of the Convention apart from the national Marine Protection, Research and Sanctuaries Act would directly interfere with the administration of a national ocean dumping program. Such a provision would open the doors to innumerable litigation proceedings whenever one was dissatisfied with decisions and permit conditions rendered under the national Marine Protection, Research and Sanctuaries Act program.

During the week of September 20, the House of Representatives passed H. R. 6113. In a supporting floor statement, a Committee member made very clear that:

> " Nothing in Section 5, or in any other provision of the compromise version of H. R. 6113 that we bring to the floor today is intended to change the nature of the London Dumping Convention to accord 'self-executing' status to the Convention, or to obviate the requirement for the Convention's legally binding provisions to be implemented domestically through promulgation of necessary rules and regulations. Currently the London Dumping Convention and its annexes have no independent status providing the basis for judicial challenge of any action by the Administration or Secretary, or of any recipient of a permit issued under the act, beyond relevant implementation through the act. This situation is intended to be unchanged by H. R. 6113."

We were also pleased to learn that Representative Clausen, ranking minority member to the Public Works Committee, further stated that:

> "It is further the strong intent of the committees that necessary dredging and disposal of dredged materials must continue in order to maintain the vital flow of commerce through our nation's ports."

United States Environmental Protection Agency Ocean Dumping Advisory Committee, 1982

In preparing for the Sixth Meeting of the Ad Hoc Scientific Group on Dumping that was held in Paris on September 27 to October 1, 1982, I had the privilege to appear before the United States Environmental Protection Agency (EPA) Ocean Dumping Advisory Committee on September 16 as representative of the AAPA for the purpose of presenting the views of AAPA and encouraging their adoption as the United States' position. These views will be discussed in more detail, shortly.

We were not entirely successful in shaping the United States' position to back those of the IAPH relating to the necessity or no necessity to develop additional standards for the assignment of substances to Annex I or II of the Convention and relating to the use of "special care" measures in the ocean dumping of polluted dredged material. However, the United States' position as adopted did support the following concepts:

- With few exceptions, impacts of ocean disposal of dredged material are mainly associated with physical effects. These effects are known to be persistent and often irreversible. The biochemical interactions, however, are infrequent with no clear trends, and bioaccumulation of metals and hydrocarbons is usually negligible. Furthermore, land-based alternatives appear to offer limited additional protection in relation to human impact as compared to ocean discharge. Most conventional land-based alternatives often result in drastically changed geochemistry of the dredged material with a subsequent enhanced release potential of chemical constituents (especially materials such as mercury and cadmium).

- Dredged material containing Annex I constituents or exhibiting Annex I properties can be safely ocean disposed. Annex I constituents can be regarded as trace contaminants through application of disposal site selection and management to minimize unacceptable adverse effects. Ocean disposal can be carried out to prevent hazard to human health, harm to living resources and marine life, damage to amenities, or interference with other legitimate uses of the sea. This approach is also in conformity with Annexes II and III of the Convention.

- Highly contaminated and toxic dredged material can be disposed of in open water if special care is exercised in site selection to ensure that the material is isolated from the biotic zone and if the approach involves significant disposal site management (e. g., capping, selection of an abiotic area).

- There is no single disposal alternative for dredged material disposal that is inherently suitable for a region or a group of projects and there is no single alternative, land or ocean based, that presumptively results in impacts of such nature that it can be categorically dismissed from consideration or arbitrarily chosen.

Sixth Meeting, Ad Hoc Scientific Group, 1982

There followed in Paris in late September of this year the Sixth Meeting of the Ad Hoc Scientific Group (AHSG) on Dumping. Our IAPH delegation again attended in an invited observer status and participated in the consideration of matters relating to dredged material. Our consultant, Dr. Willis E. Pequegnat, presented an update regarding the experience of member nations in using "special care" techniques in lessening the environmental impact of disposing in the ocean dredged material containing Annex I and other toxic substances. Several delegations questioned whether the use of "special care" measures could properly fit under the "rapidly rendered harmless" exception clause for disposal in the ocean as contained in Paragraph 8 of Annex I. Additionally, they requested that the matter be referred to the Seventh Consultative Meeting in London, to be held in February of 1983.

Another major issue taken up by the Scientific Group at the recent meeting in Paris was the question of need for developing additional criteria for classifying substances to Annexes I or II of the Convention. The Ad Hoc Scientific Group decided to make a stronger effort to develop additional criteria. Considerable support was expressed for the adoption of "numerical standards" for classification purposes based upon laboratory toxicity testing and bulk sediment analysis. The application of such standards to dredged material could have disastrous effects upon this country's ocean dumping program. It would threaten an even greater "overregulation" of dredged material--in disregard of the known characteristics of sediment that mitigate the effects of any Annex I substances that may be present. In Paris, we emphasized the different treatment that should be given dredged material. In recognition of these port concerns, we understand that the Scientific Group will invite IAPH to submit a paper addressing the special characteristics of dredged material and explaining the different treatment that is warranted. This affords an excellent opportunity for ports to affect the future treatment of dredged material under the Convention before action is taken by Contracting Parties. Any action taken under the Convention will, of course, have direct consequences in this country, since adherence to the Convention, as promulgated by national laws, is required under the Marine Protection, Research and Sanctuaries Act.

Preliminary discussions at the meeting resulted in the EPA Committee on Ocean Dumping concurring with the preparation of a report and joining with the Ad Hoc Scientific Group in requesting that AAPA and IAPH jointly prepare the report in time for consideration at the next meeting of the London Dumping Convention during the period February 14-18, 1983.

Funding the Future

As in everything these days, availability of money always is the first hurdle. We at AAPA and IAPH have held discussions with the Director of Ports and Intermodal Development, United States Maritime Administration--hoping to come forth with a grant of approximately $10,000 to partially cover the cost

of the requested research that is to be completed between now and February 14, 1983. In the meantime, we are reviewing closely our projected program and budget at AAPA.

Turning back the clock to June, 1979, and early 1980, the incipient years of the Special Dredging Committee's existence, we find that the Port of New Orleans supplemented the initial $10,000 of "seed monies" provided by the AAPA general fund by the amount of $22,357. This total of $32,357 provided sufficient funding for those early organizational years. With the organizing and early on projects, there soon developed a need for additional funds--and they were to be raised through voluntary fund-raising efforts. Since logging in our first contributed funds in September of 1980, the AAPA Special Dredging Committee has raised $147,800 as of October 15 of this year. We are particularly grateful to the International Association of Ports and Harbors for contributing $10,000 to our account in September of this year. On August 11, 1982, the Secretary General of IAPH released his second fund-raising letter request, funds from which will be applied against expenses to be incurred during the year that started in October, 1982. Concurrently, the AAPA Special Dredging Committee is under way with its own fund-raising program to cover an estimated $23,000 shortfall during the coming year in its program and budgeted support of AAPA and IAPH activities. I might add that the International Association of Dredging Companies contributed through the IAPH $2,500 this year and has pledged an additional $2,500 this coming year. At this time, our AAPA program and the IAPH Dredging Committee Ocean Dumping supporting efforts are running $40,000 to $60,000 per year.

IN SUMMARY

Summarizing 1982 to date, the AAPA Special Dredging Committee has continued to emphasize direct liaison with concerned members of the Congress and officials of the United States Army Corps of Engineers as well as other federal and state agencies and officials with an interest in or control of dredging laws and regulations. We are actively seeking the opportunity for any forum at which we can present our problems and suggest the changes in procedures and testing that are necessary. Our support of IAPH and IAPH's support of our activities of mutual interest have been most beneficial. We have been successful in publishing our position in magazines read by the dredging, business, and port industries and have been able to attend and participate in meetings and conventions representing elements in a position to influence our objectives

We look forward to an even more productive year in 1983, and an even closer relationship with our counterparts in Japan.

SOIL IMPROVEMENT BY DEEP CEMENT CONTINUOUS MIXING METHOD AND ITS EFFECT ON THE ENVIRONMENT

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INTRODUCTION

Since the coastal area of Japan, where the bulk of Japan's industrial areas and populations is concentrated, is mainly composed of soft alluvial clay, it is important to know how to improve the soft clay deposits. For this purpose, various oil improvement methods have been developed and practiced. In order to achieve rapid construction of structures with heavy super structures and to meet environmental restrictions which are strengthened year after year, new improvement techniques are needed.

The deep cement continuous mixing method, called "the DECOM" in Japanese, was developed for this purpose. This method is based on cementation rather than the usual concepts of consolidation, drainage, compaction, and replacement. Since the DECOM method enables rapid stabilization without pollution, many soil improvements using this method have been conducted.

In this paper, the problem of how to achieve the quality between previously improved and newly improved zones, called "the overlapping problem," is discussed as well as the effect of DECOM on environmental conditions using field measurements from Yokohama Harbour (Photo 1).

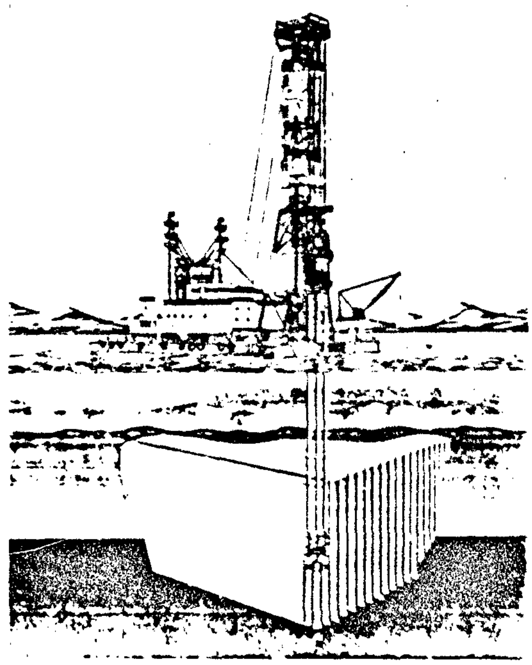


Photo 1. Yokohama Harbour

OUTLINE OF THE DECOM METHOD

In this method, slurried cement is injected into the ground and mixed with soft clay by rotation, lifting and lowering the mixer, while soft clay is hardened through hydration between hardening material and water. Then pozzolan reaction between hydration material and clay material is progressed and clay is cemented through these processes.

The DECOM method has many advantages:

a. Strength is achieved by controlling the hardening annex ratio according to the properties of the clay to be improved.

b. Strength is rapidly obtained, which enables rapid construction.

c. Deformation is very small and the effect on super structures negligible.

d. Soft clay is hardened in the field under low vibratory and low noise conditions; pollution is minimized.

e. Huge amounts of sand required by conventional improvement methods are not necessary.

Delayed Reacting Cement

The reaction rate between clay and cement is so rapid that the quality of contact between the previously improved and newly improved zone is less reliable when improved work ceases due to weather conditions or machinery troubles. In order to solve this problem, a study was conducted on delayed reaction hardening material. In the first stage, delayed settling material was studied and it was concluded that there are problems in its efficiency and cost. In the second stage, a study was conducted for a material that enables delayed hardening at the first stage but achieves the proposed strength at the final stage of t = 90 days. A good result was obtained in the laboratory and was certified in the field. The next section of this paper discusses laboratory and field test results obtained for this newly developed hardening material.

Laboratory Test Results

The requirements for the material are summarized below:

a. Hardening takes place after 3 days of mixing.

b. Unconfined compression strength, qu, at t = 90 days is equal to or more than 30-40 kg/cm^2.

c. The cost is in an allowable range.

Retarder

Normal portland cement has generally been used for DECOM because it is easily obtained. However, setting time of this material is short, within 10 hours. In order to delay the setting time, an investigation was carried out for marketing to special goods. The results are summarized in Table 1. As indicated in the table, retarder did not satisfy the requirement under conventional annex ratio. It is of course possible to achieve the requirement when cost is not considered, but this method is not practical. From this consideration, it was determined to develop a method which enables delayed hardening of cement without the addition of a retarder.

Table 1. Results of Delayed Setting Tests

Hardening Material	Annex	Annex Ratio	Setting Time
	non	0%	6h 40 min.
Normal portland cement w/c = 150%	A	0.25	7h 10
		0.40	8h 00
		0.60	8h 30
		0.80	8h 00
	B	0.25	7h 35
		0.50	8h 40
	C	0.30	8h 20
		0.45	6h 30
	D	0.35	7h 10
		0.50	6h 15
	E	0.20	6h 20
		0.30	6h 30
	F	0.20	5h 30
		0.40	8h 25
		0.60	8h 35

Delayed Hardening Material

A study for delayed hardening cement began in 1978. Two methods were noted:

a. Use of clinker material which provides a longer setting time.

b. Use of material with higher pozzolan reaction, which also enables longer setting time.

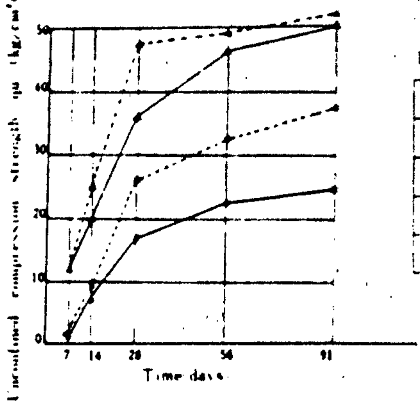
In a series of laboratory tests, both methods satisfied the requirements. Considering the lower cost and ease of manufacturing, method b was tested for use, and the material indicated in Table 2 was developed.

Table 2. Laboratory Test Results for Newly Developed Hardening Material

Hardening Material	Water*	Annex Ratio	Setting Time	Temp.	Unconfined Com. qu (kg/cm^2)				
					7 day	14 day	28 day	56 day	91 day
DM set	sea-water w/c=0.6	15 ($200\ kg/cm^3$)	86h	20°C	0.9	7.0	16.8	22.4	24.7
				30	1.6	9.3	25.9	32.5	37.2
		20 ($273\ kg/cm^3$)	6h	20	11.7	20.1	36.1	46.4	50.1
				30	11.0	25.6	47.7	49.1	52.1

* w/c = water/cement (weight ratio)
Seawater is used for water above.

This material is a kind of cement mixed with an inorganic material and is harmless. The delayed hardening processes of this material are suggested as follows:



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	Annex Ratio	Temp. °C
○—○	15%	20
○ ○	15	30
△--△	20	20
△ △	20	30

- o High Ca^{++} in liquid phase is required for hardening. When the amount of cement is small, the time to ensure hardening is long. In addition, the hardening time is often further delayed by mixing material that hinders the dissolving rate.

- o Mixing material, which contains material that hinders hardening, slowly reacts with clay and hardening slowly progresses.

- o Hardening time of clay is controlled by changing the mixing ratio when the newly developed material is used. Hardening time also depends on water content and organic content of the clay.

- o After hydration begins, strength of the clay is significantly increased with production of $Ca(OH)^2$ and thermal hydration associated with the process.

- o Hydration products are mainly calcium silicate and calcium aluminate hydrate, which are stable for long periods of time.

- o Calcium silicate hydrate changes to the more stable materials, tobermorite, gyrolite, and xonotlite, with time.

- o Pozzolan reaction with clay will continue for a long time and produces stable soil.

Field Studies

Field studies were conducted offshore of Daikoku-cho, Tsurumi-ku, Yokoham City (Figure 1) from September 1981 through March 1982.

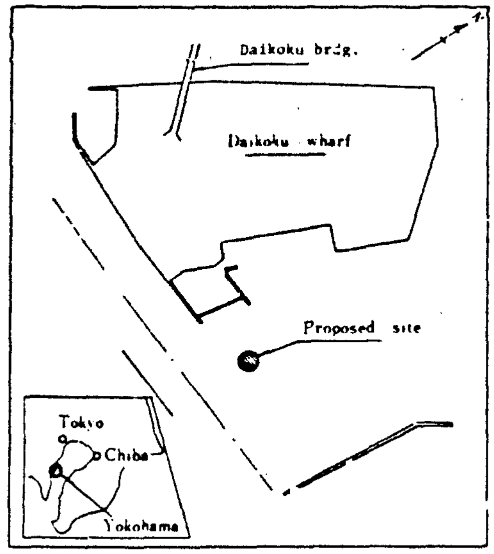

Figure 1. Guide map for the site

Soil Conditions

Before improvement, a soil investigation was carried out at a point shown in Figure 5 and the results obtained are presented in Figure 2. The properties of the clay are summarized as follows:

water content

$$\omega = 50\% - 90\%$$

unit weight

$$\gamma_t = 1.5 - 1.6 \text{ g/cm}^3$$

unconfined compression

strength, qu

$$qu = 1.15 + 0.54 \text{ z t/m}^2$$

$$(z = 0 \text{ at } -15 \text{ m})$$

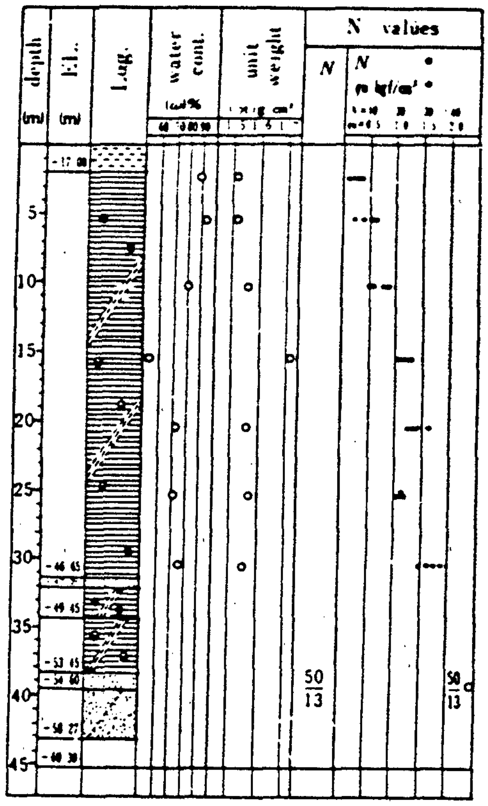

Figure 2. Soil conditions at the site

Machinery Used

The DECOM No. 2 Barge was used in this field test. This barge was manufactured to prevent sea pollution and noise as well as provide easy operation.

Design Criteria are:

Wave height : 1.0 m
Wind velocity : 15 m/sec
Current velocity : 2 knots
Allowable incline : 3° at Trim
1.5 ° at Heal

} Work Conditions

Dimensions are as follows:

a. Hull

Length : 60 m
Breadth : 30 m

Depth	:	4.5 m
Tower height (above the Upper Deck)	:	66.2 m
Draught (Design)	:	3.4 m
Displacement (Design)	:	5,800 tons
Accomodation	:	2 (for two people) 7 (for four people)
Meeting room	:	1 (for 20 people)

b. Mixing equipments

Mixing shaft : 4 (rotating)

Center shaft : 1 (fixed)

Diameter of mixing wing : 1,800 mm

Mixing motor : 900 KW × 2 set

Deep cement winch : 36 tons × 2 set, at speed of 0-16 m/min

Anchor winch : 6 30 tons at 1 m/min for construction
15 tons at 18 m/min for barge operation

c. Slurry - Plant

Silo for hardening material : 400 tons × 4

Slurry mixer : 3,500 ℓ × 2

Slurry agitator : 18,000 ℓ × 1

Slurry injection pump : 600 ℓ/min × 6

d. Engine

Main generator engine : type NKK-SEMT-PIEL STICK
S.H.P. 4,500 PS
Revolution 514 r.p.m.

e. Electric installation

Type	:	Horizontal, deep-proof, separately ventilated, revolving-field, salient-pole type AC generator
Output	:	3,750 KVA (3,000 KW)
Voltage	:	3,300 V
Frequency	:	60 HZ
Revolution	:	514 r.p.m.

General arrangement of the DECOM No. 2 barge and flow of plant are indicated in Figures 3 and 4.

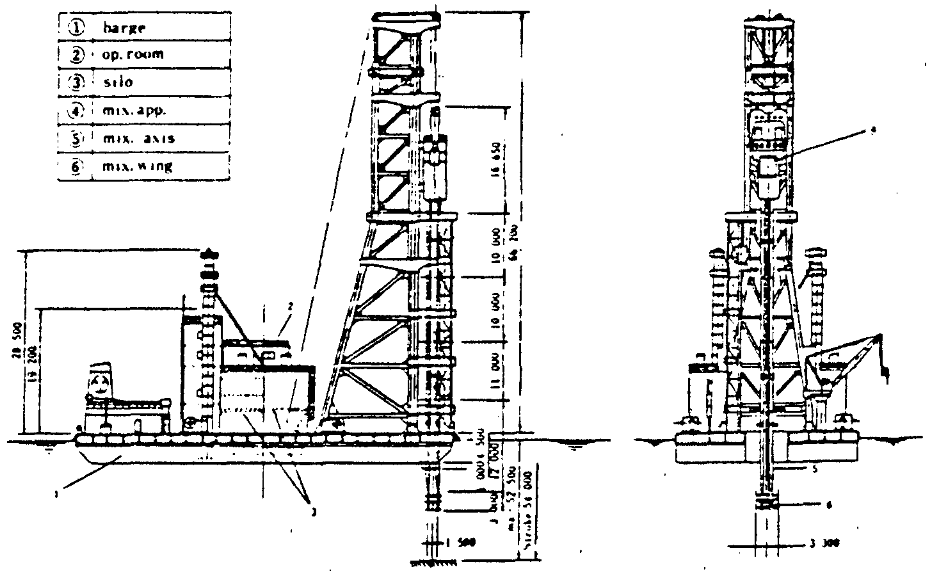

Figure 3. Outline of the DECOM Barge 2

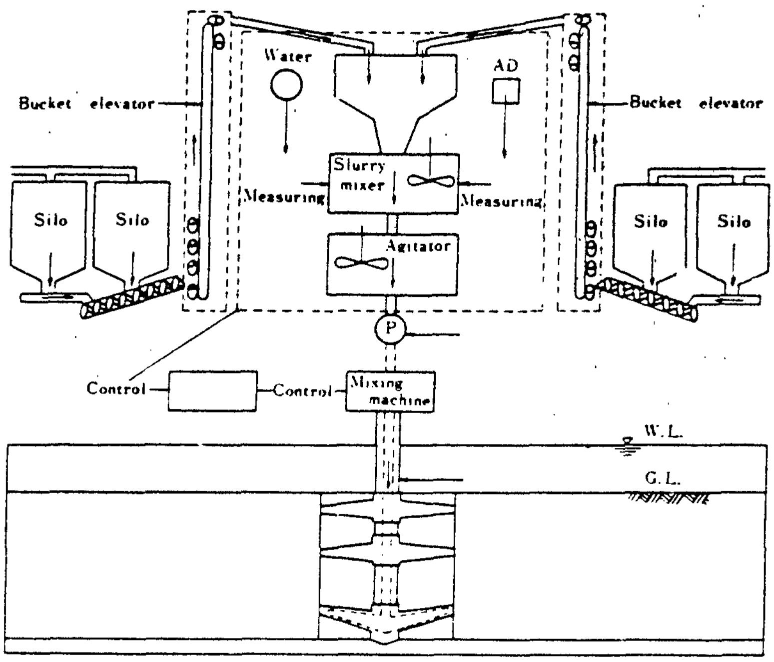

Figure 4. Flow of plant

Specification for Soil Improvement

The area of an improved pile is 9.48 m^2 and 6 piles were constructed in one cycle under the spacing shown in Figure 5. The sequence of improved pile is shown in Table 3 and the connection of each improved pile was conducted using 5 methods within 96 hours.

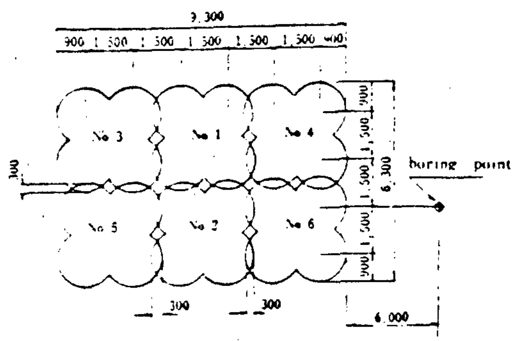

Figure 5. Spacing of improved piles

Table 3. Sequence of Improved Pile

Penetration Date	No. of Imp. Pile	Test Conducted
1st day	No. 1. 2	
2nd	No. 3	connection after 24 hours
3rd	No. 4	48
4th	No. 6	72
5th	No. 5	96

Specifications for improved piles are shown in Table 4. As shown in Figure 6, slurry cement was placed during penetration and then mixed with clay by lifting the mixing wing.

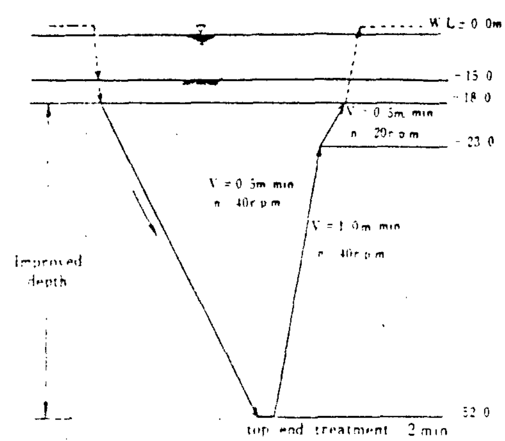

Figure 6. Sequence of improved pile operation

Table 4. Specification for Improved Pile

Items	Specification
Penetration speed	0.50 - 0.25 (m/min)
Withdrawal speed	1.00 - 0.50 (m/min)
Rotating rate	20 - 40 (r.p.m.)
Improved depth	-18 - 52.0 m (DL)

The composition of newly developed hardening material is as shown in Table 3. Two methods, 210 kg/m^3 and 160 kg/m^3, were adopted. Water-cement ratio was 60% for each method using seawater.

Table 5. Composition for Newly Developed Material

	Composition (a)	Pile No.
DM set	210 kg/m^3 160 kg/m^3	No. 1 No. 2,3,4,5, & 6

Results or Field Test

The field test results are as follows:

a. Construction quality

- Torque of mixing apparatus

  Torque induced during mixing is summarized in Figure 7. The torque during penetration was smaller by 100 - 200 amperes (A) when compared with that induced using normal portland cement. This difference during withdrawal was significant reaching 150 - 600 (A) and was caused by rapid hardening when normal portland cement is used. The torque indicated a value of 100 to 200% of allowable capacity in the use of normal portland cement. On the other hand, the torque in the use of newly developed material did not reach 100% except when penetration reached a hard layer with N values more than 50. In addition, the torque for the connection part did not show any significant difference within 96 hours. This demonstrates the efficiency of the newly developed material.

- Loading to mixing apparatus

  Loads on mixing apparatus are summarized in Figure 8. The same torque trend was observed. The load when using normal portland cement suddenly decreased at around -40 m in penetration, and significantly increased reaching 560 - 620 tons which exceeded the self-weight of mixing apparatus (480 tons) in withdrawal. In contrast, the load when using newly developed material was within the self-weight, regardless of time of 0 - 96 hours.

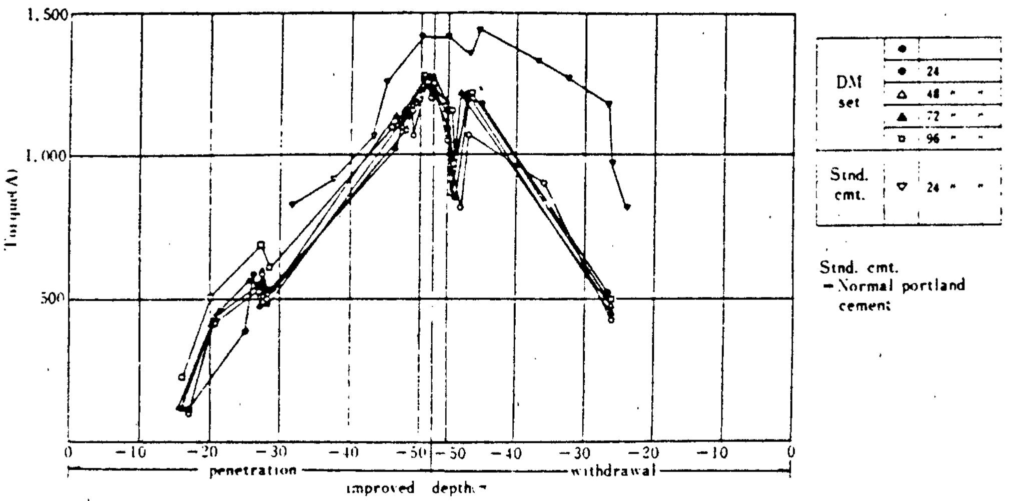

Figure 7. Torque mobilized du... g operation plotted versus depth

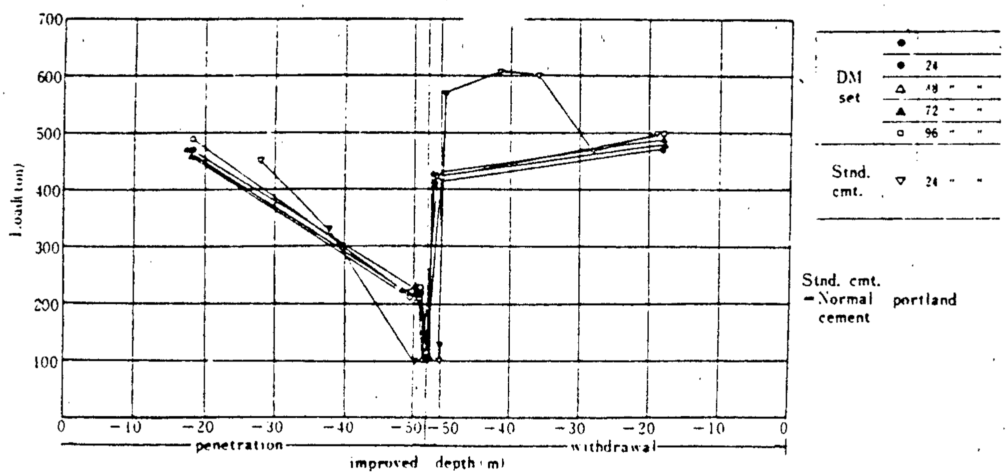

Figure 8. Load mobilized through operation versus time

o <u>Accuracy</u>

In the DECOM method, improved piles were constructed by overlapping to make the ground a unified improved body. Therefore, accuracy of construction is an important checkpoint. Figure 9 indicates the connected conditions, and the barge location is determined by transit survey. The location of the mixing wing was measured using an automatic inclinometer. From Figure 9 it can be observed that reliability of the connected zone is high enough regardless of time (0-96 hours) when the newly developed material is used.

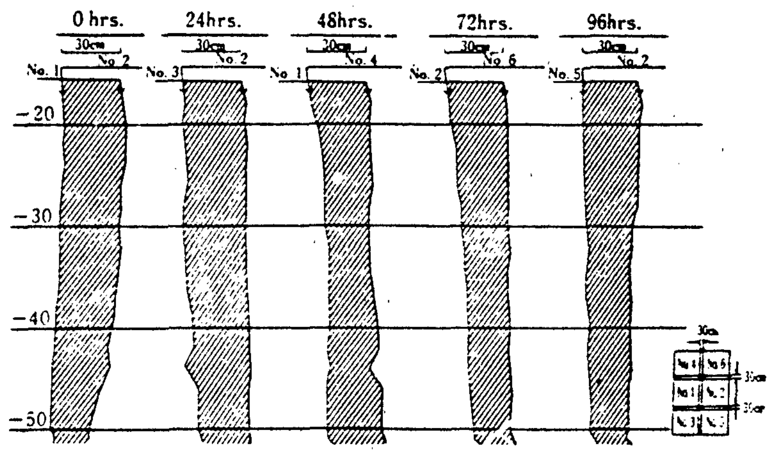

Figure 9. Connected conditions between piles versus time

<u>b</u>. Results obtained from check boring and soil test

o <u>Results of check boring</u>

Continuous sampling was conducted at 5 points shown in Figure 10 to certify the connected condition and the physical and strength properties of the improved soil. Of the 5 borings, two were inclined (one for the check of connected conditions). The results obtained from the inclined boring are shown in Figures 11 and 12. As shown in the figures, the connected zone is unified regardless of time (0-96 hours).

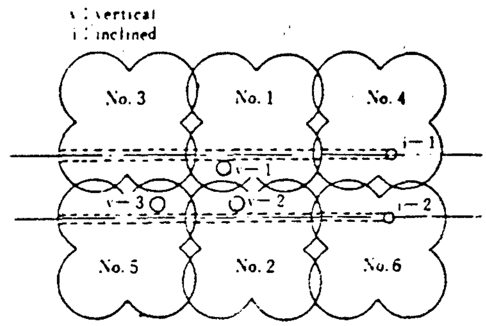

Figure 10. Locations of check boring

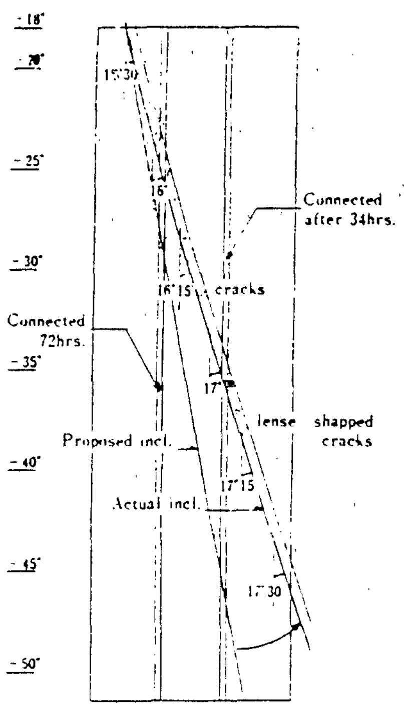

Figure 11. Inclined boring (No. 1)

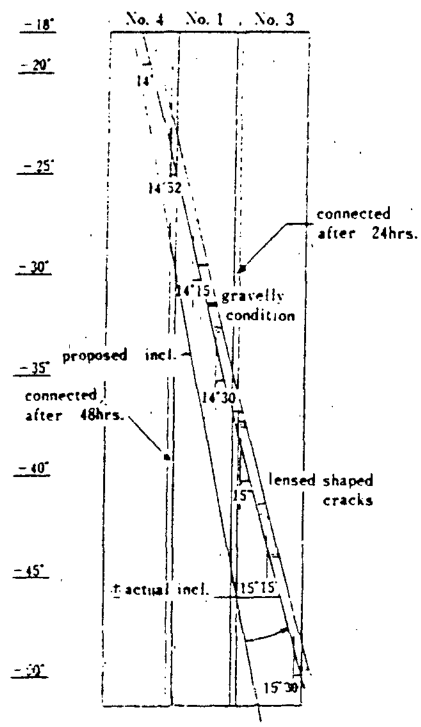

Figure 12. Inclined boring (No. 2)

o <u>Water content and unit weight of improved soil</u>

Water content after improvement ranged from 40 to 80% (Figure 13) and indicated smaller values by 10–20% than the values before improvement (ω = 50–90% before improvement). On the other hand, unit weight after improvement did not show any significant difference than before improvement (Figure 14).

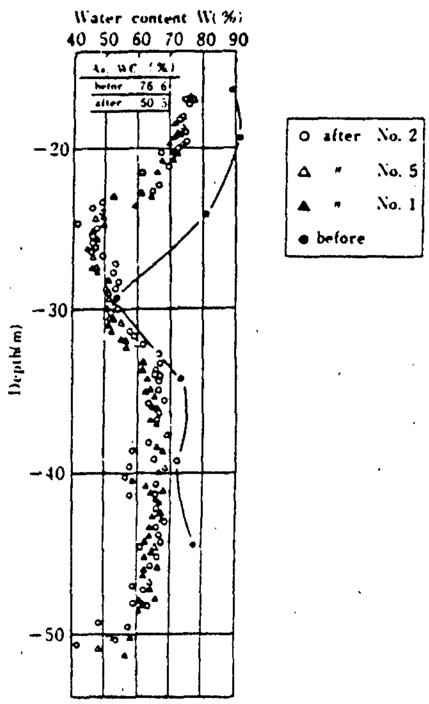

Figure 13. Water content versus depth

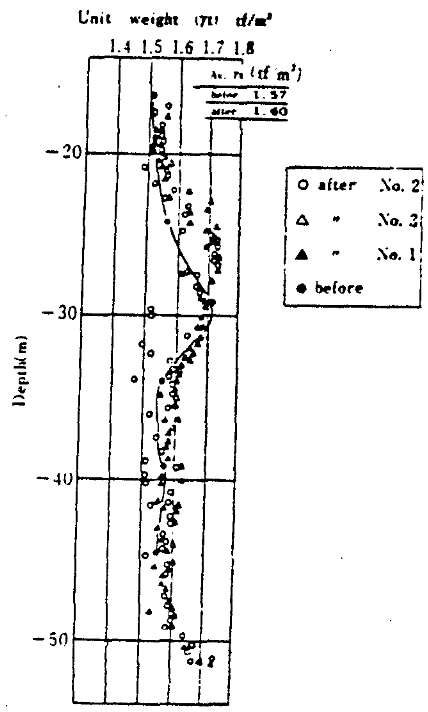

Figure 14. Unit weight versus depth

o Unconfined compression strength

In Figure 15, unconfined compression strength before and after improvement is compared. The values of qu are those after 3 months of improvement. The values of qu for α = 160 and 210 kg/m^3 were 56.9 and 75.4 kg/cm^2, respectively. Those values satisfy the design criteria.

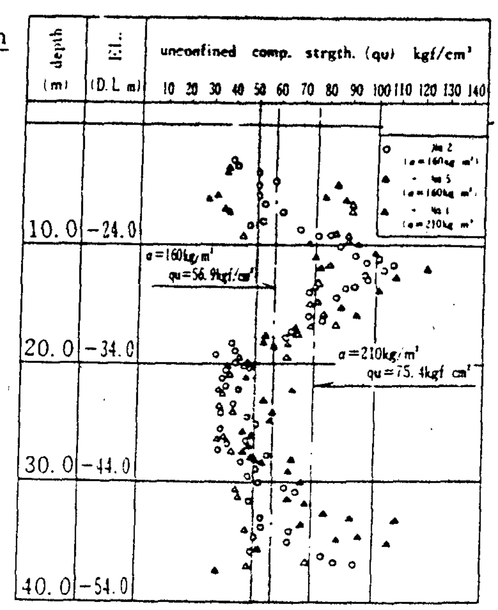

Figure 15. Unconfined compression strength plotted versus depth

c. Temperature of improved soils

A thermometer was installed at three depths: -19.8, -22.3, and -24.8 m of No. 5 pile. The results are presented in Figure 16. A significant difference can be observed in temperature of the soil improved by normal portland cement and the newly developed material. The temperature of soil treated with the new material rose slowly, reaching 40^{o}-48^{o} after 2 weeks, whereas a temperature of 45^{o} was measured after only 1 day when standard portland cement was used.

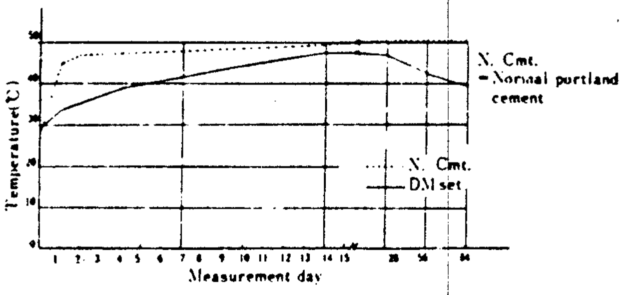

Figure 16. Results of temperature measurement

EFFECTS ON THE MARINE ENVIRONMENT

Water Quality and Sediment

The water quality and sediment investigation was conducted in March 1977 in Tokoyo Bay (Figures 17 and 18). Items covered during the investigation are listed in Table 6.

Meteorological and Oceanographical Conditions

Results observed about the general meteorological and oceanographical conditions were as follows:

Weather

The weather was either cloudy or fine.

Wind

Direction and velocity of wind were E - NE and 4.4 - 5.8 m/sec (4.8 m/sec average).

Temperature

The air temperature reached a low of 4.3°C before carrying out and 10.1 - 15.4°C during and after. Water temperature reached a low of 7.6°C before and 8.8 - 10.6°C during and after.

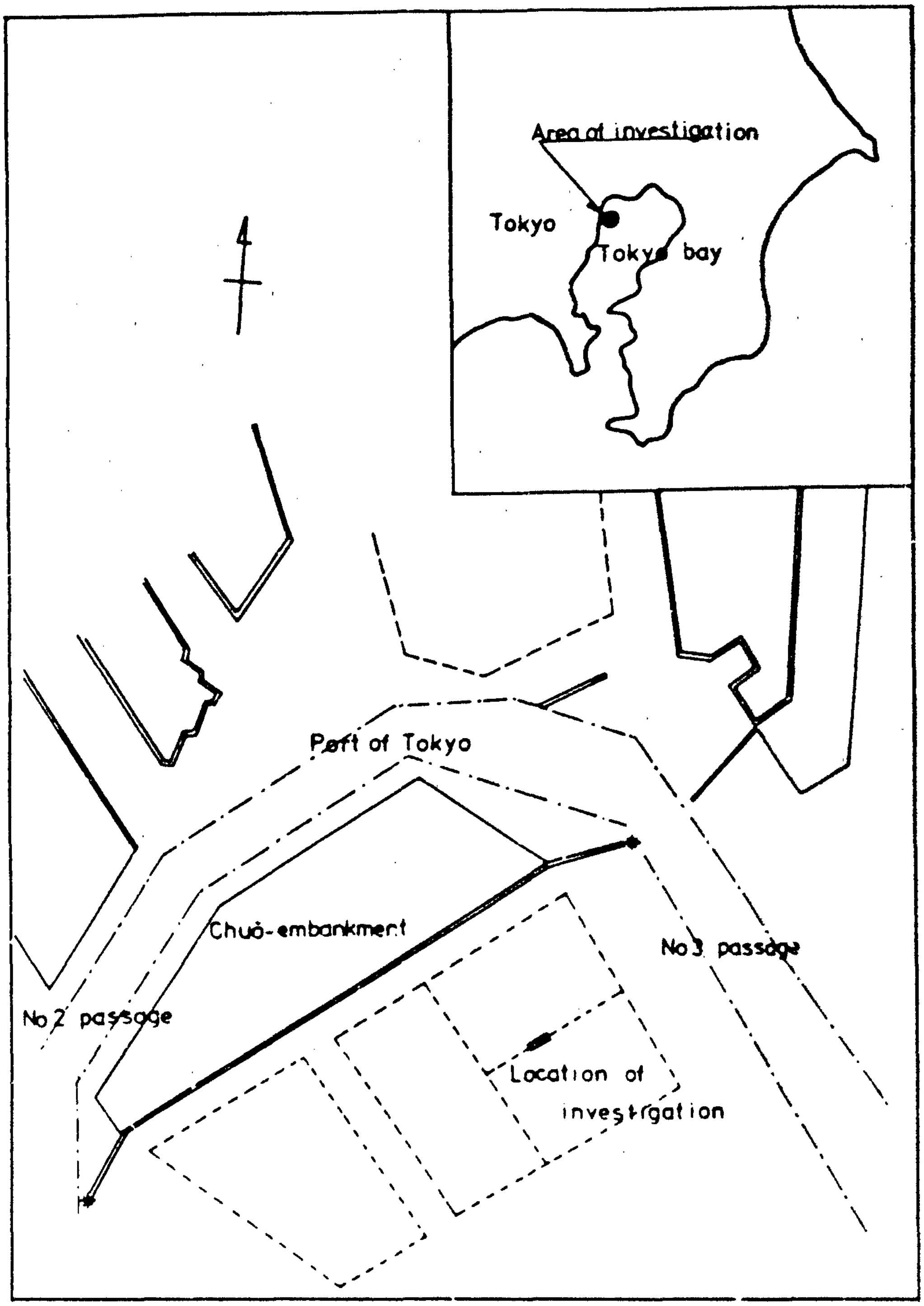

Figure 17. Location of investigation

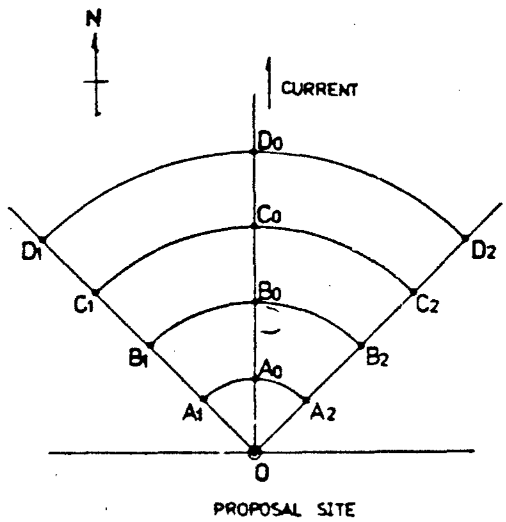

Figure 18. Stations of investigation

Current

Before operation the current velocity was 0.04 - 0.15 m/sec (0.10 m/sec average) and the direction of current was nearly NNE. During operation the velocity was 0.01 - 0.11 m/sec (0.06 m/sec average) and the direction was nearly N.

Depth

The sea depth in the investigation area was 7.0 - 10.2 m (9.0 m average).

Water

Water quality results were as follows:

Transparency

Before operation the transparency values were 1.10 - 1.35 m (1.25 m average); 2 hours after operation commencement low values of 0.8 - 1.30 m (1.03 m average) occurred and effects by the operation were recognized. However, soon after the values recovered to 1.20 - 1.50 m (1.30 m average).

Turbidity

Turbidity measurements are shown in Figure 19. Before operation the turbidity averaged 4.1 ppm at the upper layer, 3.0 ppm at the middle layer, and 2.5 ppm at the lower layer. At 2 and 4 hours after operation the nearer the investigation stations were to the proposal site, the higher values they

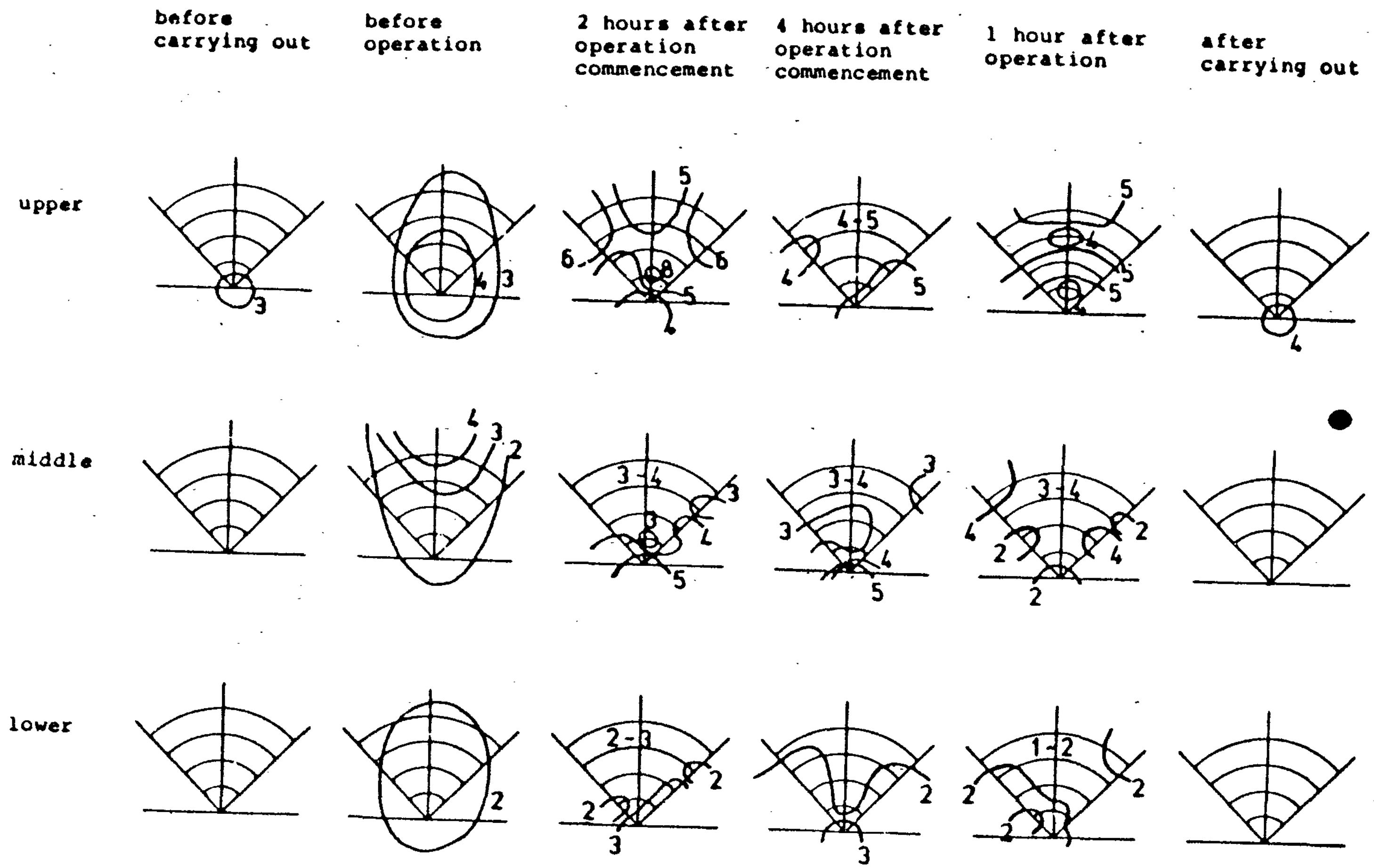

Figure 19. Distribution of turbidity (ppm)

Table 6. Contents of Investigation

Stations		Items	Time
Before carrying out	St.0	WATER Appearance, transparency, smell, pH, DOC, BOD, DO, turbidity, SS, n-Xexane extract SEDIMENT Appearance, smell, pH, COD, Ignition Loss	28 Jan 1977 before carrying out
During carrying out	St. 0 St. $A_o - A_2$ St. $B_o - B_2$ St. $C_o - C_2$ St. $D_o - D_2$	WATER Appearance, transparency, pH, COD, turbidity, SS, direction and velocity of current and wind	14-15 Mar 1977 before operation 2, 4 hours after operation commencement 1 hour after operation
After carrying out	St. 0	WATER Appearance, transparency, smell, pH, COD, BOD, DO, turbidity, SS, n-Xexane extract SEDIMENT Appearance, smell, pH, COD, Ignition Loss	29 Mar 1977 after carrying out

showed, over 4.0 ppm at 0 m (St. 0) and 50 m (St. A_0) on average. Furthermore, the upper layers showed higher values of 4.1 - 5.6 ppm. The middle and lower layer showed lower values of 3.0 - 3.5 ppm and 2.0 - 2.6 ppm, respectively, not much change when compared with before operation values.

SS (Suspended Solids)

Before operation SS values averaged 5.0 ppm, 3.3 ppm, and 4.3 ppm at the upper, middle, and lower layers, respectively; however, during operation SS concentrations increased about 1.0-2.4 ppm for the upper and middle layers. Simultaneously it was recognized that 2-3 ppm increased at each layer near the proposal site. One hour after operation the values returned to the before operation values at every station and layer.

pH

The pH results are shown in Figure 20. Before carrying out pH reached a low value of 7.6 at the proposal site; this value did not satisfy the environmental criteria in this sea area. However, at stations other than the proposal site, pH values averaged 8.1-8.3. At 2 and 4 hours after operation commencement and 1 hour after operation the average values of 8.0-8.2 were generally observed. A tendency was recognized for higher values to appear at middle and lower layers than at upper layers and for higher values to appear at 2 and 4 hours after operation commencement than at 1 hour after operation. Some effects caused by the soil improvement method were recognized.

COD (Chemical Oxygen Demand)

Before operation COD values averaged 6.2, 1.5, and 4.4 ppm at the upper, middle, and lower layers, respectively. At 2 and 4 hours after operation commencement the COD values of 2-2.6 increased mainly near the upper layer at the proposal site (St. 0) and station of 100 m (St. B_0). At the lower layers changes were scarcely recognized.

DO (Demand Oxygen), BOD (Biological Oxygen Demand), n-Hexane Extract

Both before and after carrying out the values of DO, BOD, and n-Hexane extract showed, respectively, 7.2-7.6 ppm, 2.7-3.5 ppm, and below 0.5 ppm; the changes were scarcely recognized.

Sediment

The values of COD and ignition loss had scarcely changed after carrying out. However, the tendency was recognized for the values of pH and water volume in bottom mud to increase from 8.2 to 10.8 and from 138.9% to 240.1%, respectively.

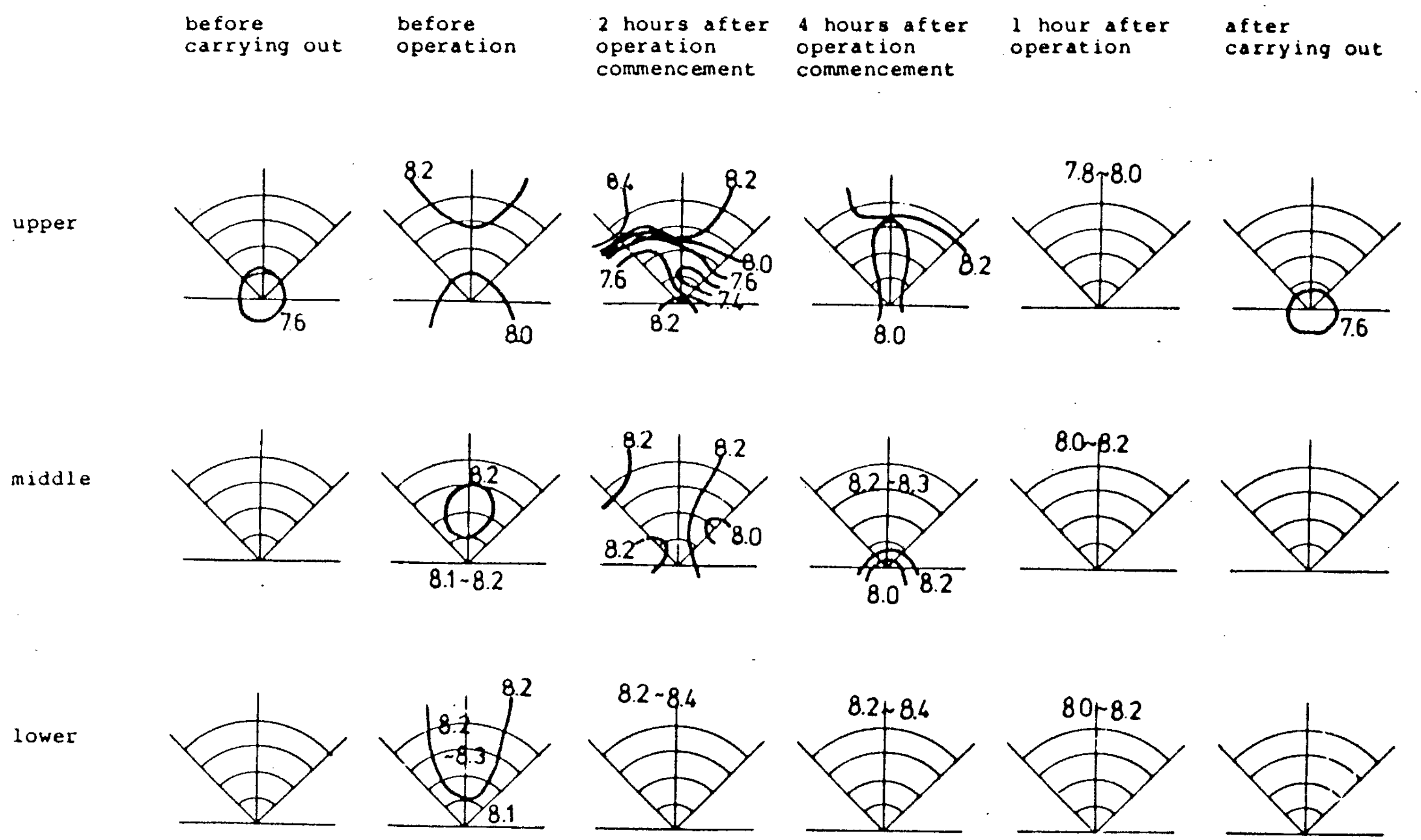

Figure 20. Distribution of pH

Discussion

Results obtained in this investigation indicated that the effects by this soil improvement method (DECOM Method) were approximately as follows: 1) new additional turbidities of 1-2 ppm, and 2) rising values of pH of 0.4-0.6 surrounding the proposal site.

These effects were mainly caused by: 1) stirring up of the bottom sediment into the upper layer by the mixing wing, 2) stirring up the bottom sediments by moving the mixing shaft in continuous operation, 3) outflow of bottom sediments and cement slurries attached to the shaft and mixing wing when pulled up from the bottom for removing, and 4) outflow of bottom sediments and cement slurries attached to the shaft and mixing wing when washed after operation.

Furthermore, pH in the upper layer of bottom sediment showed a 2.6 rise which was believed to be caused by the soil improvement method itself using cement slurry.

These effects, however, were mostly temporary and disappeared soon after carrying out. The pH values in the upper layer of bottom sediments certainly returned to the values before carrying out after about 3 months.

Noise

Noise from the DECOM-1 barge was investigated in November 1977 in Tokoyo Bay.

This investigation was carried out at 5 stations on the vessel and 1 station on the sea. All engines of DECOM-1 barge were in operation. Consequently, the levels of noise were about 80-90 dB on the vessel and 67 dB on the sea 50 m distant from the barge (Figure 21). From data obtained in other sea areas, the noise levels at distant stations were approximately 60-65 dB at 100 m, 55-60 dB at 200 m, and 40 dB at 1000 m.

These results showed that the value measured at 200 m satisfied the criteria of noise levels of 60 dB in a dwelling area.

SUMMARY AND CONCLUSIONS

A series of laboratory and field tests for soil improvement using the newly developed hardening material were described as well as the effect on the marine environment. The following conclusions and suggestions are made from this study.

(1) Because of delayed hardening of the newly developed material, it was found that a connected condition of sufficient quality can be achieved even if constructed 96 hours after the previous improvement.

DeCoM-1 vessel

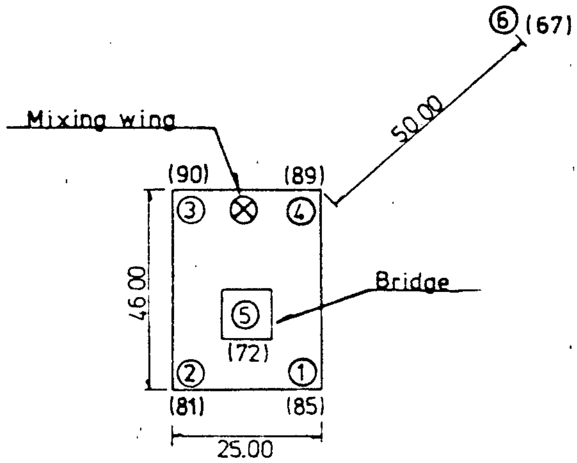

Figure 21. Stations and results measured of noise
(1 ~ 6 : stations ( ): results (dB))

(2) Therefore, the severe time requirement to connect the zone within one day can be loosened. The coefficient β , which indicates reliability of the connected part, can be expected to have a larger value than conventional values such as β = 0.5 - 0.6 (for the type of slurry jetting through withdrawal) and β = 0.8 - 0.9 (for the type of slurry jetting through penetration).

(3) Unconfined compression strengths of improved soil treated with the newly developed material were 56.9 kg/cm^2 (α = 160 kg/cm^3, t = 90 days) and 75.4 kg/cm^2 (α = 210 kg/cm^2, t = 90 days). These values satisfy the design criteria.

(4) It was also found that the soil improvement with this material did not significantly affect the marine environment.

(5) It can be concluded, therefore, that the DECOM method with the newly developed hardening material has various advantages over the conventional portland cement method.

A COMPARISON OF METHODS FOR ESTIMATING NUTRIENT RELEASE FROM LAKE SEDIMENTS

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ABSTRACT

This paper discusses four methods for estimating the rate of NH_4-N release from sediment. Precision of the NH_4-N release rate determinations was compared by examining the variances among the laboratory sediment core method, the in situ sediment core method, the in situ chamber method, and the mathematical model method.

The in situ core method reflected the least precision of the NH_4-N release rate determinations.

Statistical tests showed that the NH_4-N release rates calculated from the NH_4-N gradient between the overlying water and the interstitial water of the 0- to 2-cm layer ($\Delta\ell$ = 1.0 cm) in the uppermost sediment did not significantly differ from those estimated by the laboratory core method and the in situ chamber method.

The mathematical model calculating the NH_4-N gradient between the overlying water and the interstitial water in the uppermost layer of sediment could well be applied to other lake systems.

INTRODUCTION

We cannot ignore the effects of nutrient release from bottom sediments, particularly in shallow lakes, on excessive growths of algae in lakes.[1-3] Although many lake restoration programs, such as wastewater diversion and advanced wastewater treatments, have been implemented, water quality has not been improved to the desired level in some lakes because of the nutrient release from the sediment.[4,5]

In implementing lake restoration programs or eutrophication control programs, it is necessary to quantify the magnitude of nutrient release from lake sediments.

The methods for estimating nutrient flux from lake sediments are classified into two types. In the first type, nutrient flux is estimated from the measurement of the rate of increase in nutrient concentration of overlying waters in artifically isolated in situ or laboratory sediment water systems.[5-13] In the second type, flux is calculated from Fick's law, i.e., flux is proportional to the gradient of nutrient concentration at the sediment-water interface.[7,14]

There are three methods of the first type: laboratory sediment core method, in situ sediment core method, and in situ chamber method. The laboratory core method is designed to simulate the lake bottom as closely to the natural conditions as possible and to measure the sediment-water nutrient flux. In the in situ sediment core method the sediment-water nutrient flux is measured by using the sediment cores placed near the lake bottom. The in situ chamber method is designed to isolate a portion of bottom sediment and its overlying water by an in situ chamber and measure the change in nutrient concentration of its overlying water.

Many studies have reported the rates of nutrient release from the sediment using one or two of the above-mentioned methods. However, the precision of the methods for estimating sediment-water nutrient flux has not been evaluated. In this study we quantified the magnitude of the sediment-water nutrient flux using the above methods and compared the precision of the methods.

MATERIALS AND METHODS

Study Area

This study was initiated to investigate the sediment-water nutrient flux in Lake Yunoko, a dimictic lake located in Nikko National Park. Table 1 shows the morphometric data in Lake Yunoko. Intensive limnological monitoring and

Table 1. Summary of morphometric and hydrologic characteristics for Lake Yunoko

Parameter	Lake Yunoko
Surface Area of Lake (km^2)	0.35
Lake Volume (m^3)	2.62×10^6
Mean Depth (m)	7.4
Maximum Depth (m)	14.5
Length of Lake (km)	3.8
Water Retention Time (days)	40

modeling efforts have been conducted to assess the response of the lake to the advanced wastewater treatment aimed at phosphorus removal, the ban of phosphorus detergents, and the dredging of a part of lake bottom sediment.[15,16] These investigations have revealed Lake Yunoko to be eutrophic. Chlorophyll a concentrations often exceed 20 μg/ℓ. Total nitrogen and total phosphorus concentrations in the epilimnion range from 0.2 to 0.8 mg N/ℓ, and from 0.02 to 0.10 mg P/ℓ, respectively. The study station, shown in Figure 1, is 8 m deep. In this investigation, NH_4-N release rates were estimated at this station in August of 1982.

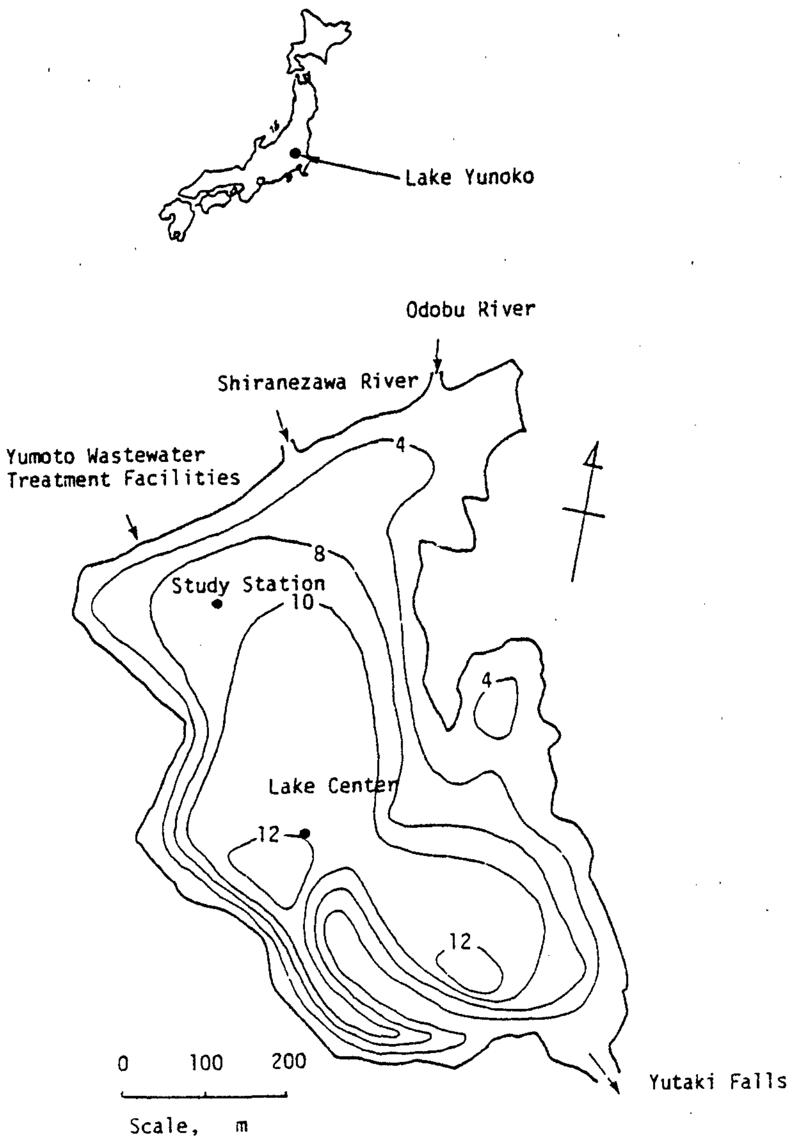

Figure 1. Location of study station and bathymetric map for Lake Yunoko

Laboratory Sediment Core Method

Sediment-water nutrient flux is estimated by measuring NH_4-N concentration in the overlying water of the sediment core placed in the laboratory.

Sediment cores were taken with the coring device shown in Figure 2. The sediment core was placed in the dark and its ambient temperature was maintained within ±2°C of that of the lake bottom where the core was taken. Dissolved oxygen concentration was maintained close to that of the lake bottom by passing mixed nitrogen-oxygen gas with various ratios through the overlying water. The apparatus is shown in Figure 3.

Water temperature and dissolved oxygen in the hypolimnion during this investigation ranged from 10° to 11°C, and from 7 to 8 mg/ℓ, respectively. In this study, water temperature was maintained at 10°C ± 2°C. Aerobic condition was maintained by passing compressed air through the overlying water.

The overlying water was periodically sampled using a syringe from the upper part of the core, and then filtered through a glass-fiber filter (Whatman GFC; pore size = 1 μm). The filtrate was analyzed for NH_4-N. Ammonia was determined by the automated colorimetric phenate method.[17] The filtrate of lake water taken at the study station was added into the overlying water to compensate for the decrease in the volume of that after sampling.

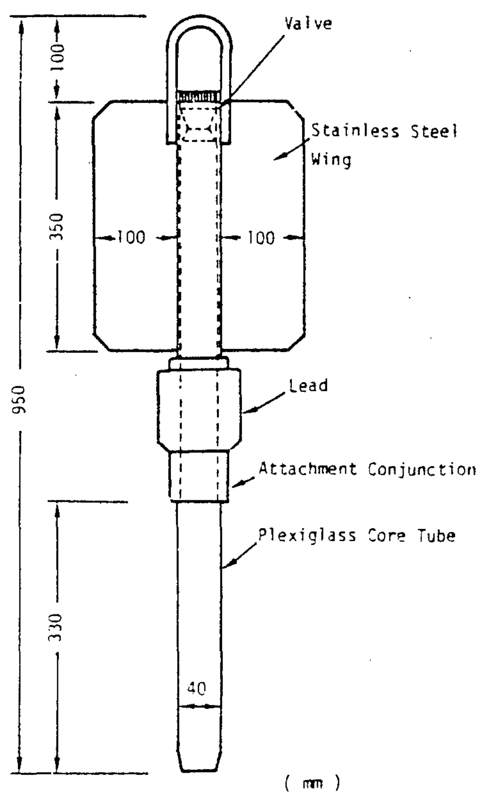

Figure 2. A coring device

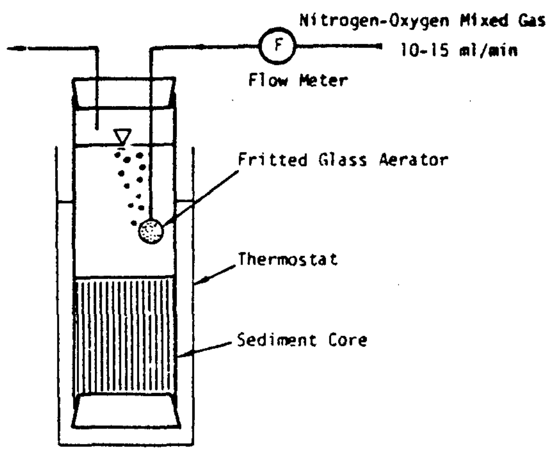

Figure 3. An experimental apparatus used in the laboratory core method

The cumulative amount of NH_4-H released from the lake sediment to the overlying water at each sampling was calculated by

$$r = \frac{V(Cn - Co) + \sum_{j=i}^{n} v(C_{j-1} - Ca)}{A} \tag{1}$$

where r = the cumulative amount of NH_4-N released from the lake sediment (M/L^2)*; V = volume of overlying water of the sediment core (L^3); Cn = NH_4-N concentration at n'th sampling in the overlying water (M/L^3); Co = initial NH_4-N concentration in the overlying water (M/L^3); v = volume of overlying water sampled for NH_4-N analysis (L^3); Ca = NH_4-N concentration in lake water added into the overlying water (M/L^3); and A = area of sediment-water interface of the sediment core (L^2).

NH_4-N flux was estimated from the rate of increase in the cumulative amount of NH_4-N released.

In Situ Sediment Core Method

Nutrient flux is estimated by measuring NH_4-N concentration in the overlying water of the sediment core placed near lake bottom. This method is similar to the laboratory sediment core method. However, neither the dissolved oxygen control nor the mixing of the overlying water by passing the mixed gas were conducted in this method.

* M = mass, L = length.

Sediment cores were periodically pulled onboard. A portion of the overlying water was sampled after the overlying water was mixed homogeneously. NH_4-N was determined the same way as the laboratory core method.

In Situ Chamber Method

The in situ monitoring of the sediment-water nutrient exchange process is performed using a submerged chamber as shown in Figure 4.

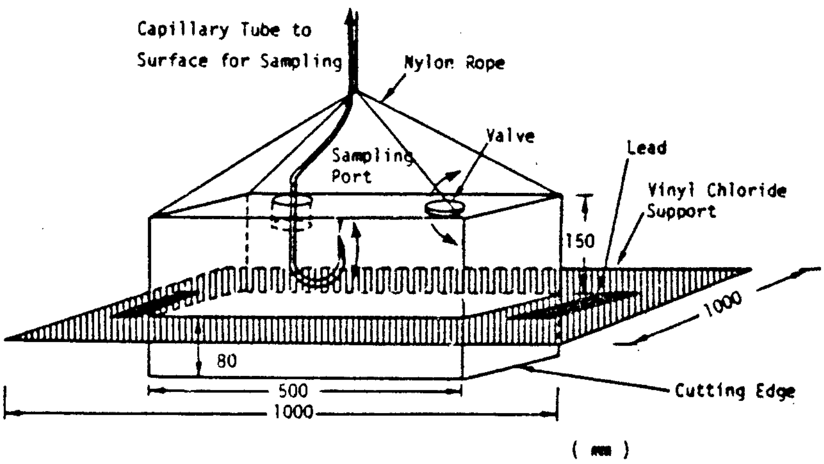

Figure 4. The submerged chamber used in the in situ chamber method

Chambers made of vinyl chloride are placed on the lake bottom. The chamber isolates a portion of the bottom sediment and its overlying water. The overlying water within the chamber is mixed homogeneously by repeated (4 times) withdrawal and injection of a part (ca. 50 ml) of overlying water in the chamber using a syringe before sampling. In preliminary experiments, we confirmed that the overlying water within the chamber was mixed well by this method. The overlying water was periodically sampled with a syringe onboard, and then filtered with the same procedure as the laboratory sediment core method.

Because the volume of the overlying water within the chamber was far greater than that of the water sampled for nutrient analysis, the second term of Eq. (1) was neglected. The cumulative amount of nutrient released from the lake sediment to the overlying water within the chamber at each sampling was calculated by

$$r = \frac{V(Cn - Co)}{A} \tag{2}$$

where r = the cumulative amount of nutrient released from lake sediment (M/L^2); V = volume of the overlying water of a chamber (L^3); Cn = NH_4-N concentration at n'th sampling in the overlying water (M/L^3); Co = initial NH_4-N

concentration in the overlying water (M/L^3); and A = area of sediment-water interface in a chamber (L^2).

Mathematical Model Method

In estimating transport of dissolved species, such as Cl^-, Na^+, SO_4^{2-}, from sediments to overlying water, the Fickian description of the transport has been generally utilized. In the Fickian description, the flux from sediment is directly proportional to concentration gradients of dissolved species. A theoretical nutrient flux was calculated from

$$R = -\phi \cdot D_t \cdot \frac{\partial C}{\partial z} \qquad (3)$$

where R = nutrient flux ($M/L^2/T$)*; ϕ = porosity of the sediment (dimensionless); D_t = effective diffusion coefficient at t°C (L^2/T); and $\partial C/\partial z$ = the gradient of nutrient concentration at sediment-water interface (M/L^4). We cannot determine the accurate gradient of nutrient concentration at the sediment-water interface experimently because the sediment-water interface is very delicate and easily disturbed during sampling. Hence, the concentration gradient at the sediment-water interface was estimated from the concentration gradient between the overlying water and the interstitial water in the uppermost sediment layer (usually the top 1 or 2 cm of sediment)

$$-\frac{\partial C}{\partial z} = \frac{C_{in} - C_{over}}{\Delta z} \qquad (3)'$$

where C_{in} = NH_4-N concentration of interstitial water in the uppermost layer of sediment (M/L^3); C_{over} = nutrient concentration in overlying water (M/L^3); and Δz = the distance from the bottom sediment surface to the central plane of the uppermost sediment layer (L).

Many researchers have attempted to evaluate the diffusion coefficient in sediment using various methods, but the estimate values ranged widely from 1×10^{-4} to 10^{-7} cm^2/sec.[7,8,18,19] The nutrient exchange of the sediment-water interface is a result of a combination of physical, chemical, and biological processes such as molecular diffusion, bioturbation, physical mixing, and adsorption-desorption. These processes are complex and difficult to measure separately. Accordingly, at present, it is difficult to evaluate effective diffusion or transport coefficients incorporating the above-mentioned processes.

Freedman and Canale[7] applied the correlation of diffusion coefficient with porosity shown by Manheim[18] to the sediment of White Lake and evaluated flux from the sediment. Lerman[19] had formulated a relationship between

* T = time.

diffusion coefficients and porosity using data from Manheim.[18] The value of the diffusion coefficient D is approximately directly related to ϕ^{2}[2,19]

$$D = D_0 \cdot \phi^2 \tag{4}$$

where D_0 is the value of the diffusion coefficient in the bulk (that is, when $\phi = 1$). D_0 of ammonia is 9.8×10^{-6} cm^2/sec.

Diffusion coefficients increase directly proportional to temperature[19]

$$D_t = D(1 + \alpha t) \tag{5}$$

where α = empirical constant (1/°C); and t = temperature (°C). The empirical constant of ammonia is 0.04. In this study we calculated diffusion coefficients from Eq. (3), Eq. (3)', Eq. (4), and Eq. (5).

Sampling of interstitial water in the uppermost sediment was conducted as follows. Sediment cores were taken with a coring device and immediately transported to the laboratory. After the overlying water was removed carefully, minimizing disturbance of the sediment-water interface, the sediment core was sectioned into 1- and 2-cm slices. These slices were inserted into the centrifuge-filter (Whatman GFC) tubes (shown in Figure 5) and centrifuged at 3,000 rpm for 15 minutes with sediment-water interface temperatures ±2°C. The filtrate was analyzed for NH_4-N with the same procedure as overlying water.

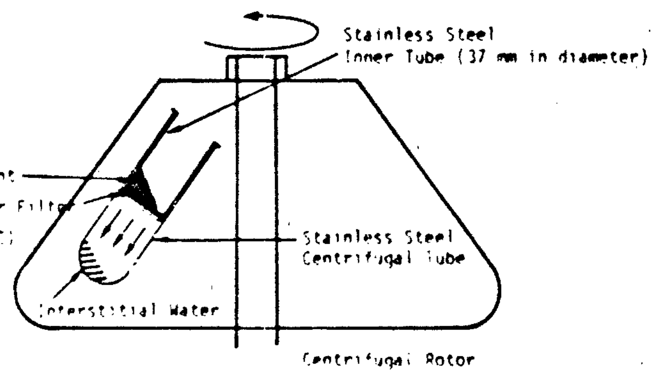

Figure 5. The centrifuge - filter system for sampling interstitial water in sediments

RESULTS AND DISCUSSION

The release rates of NH_4-N were evaluated simultaneously by the laboratory sediment core method, the in-situ sediment core method, and the in-situ chamber method. Both in the laboratory and in-situ core methods, six cores were used simultaneously to estimate precision of these methods for the determination of NH_4-N release rates. In the in-situ chamber method, four submerged chambers were set simultaneously on lake bottom.

Results from these experiments are depicted graphically in Figures 6-8. All of these experiments showed that the cumulative amounts of NH_4-N released from sediment were directly proportional to elapsing time.

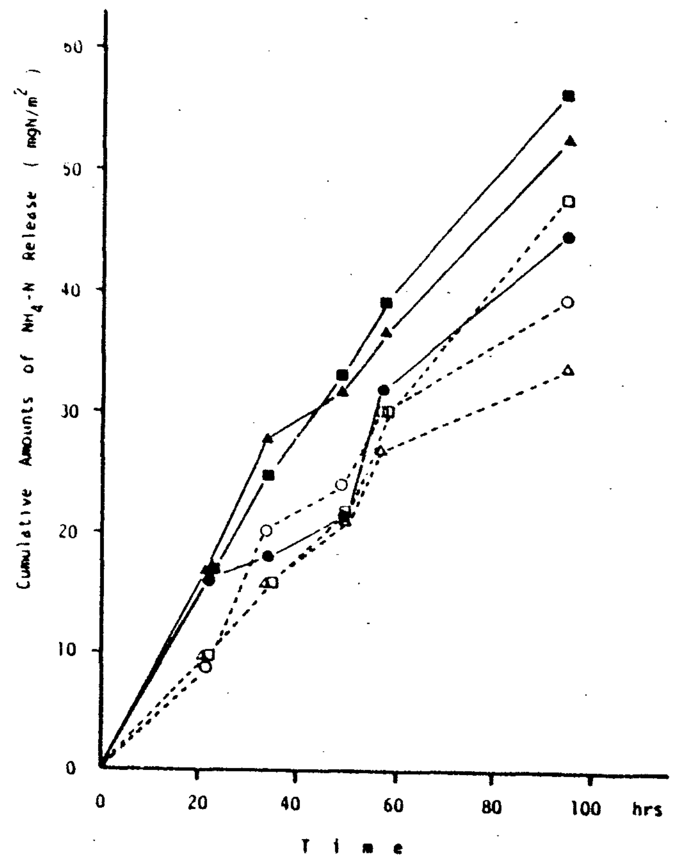

Figure 6. Cumulative amounts of NH_4-N release measured by the laboratory core method, August 21-25

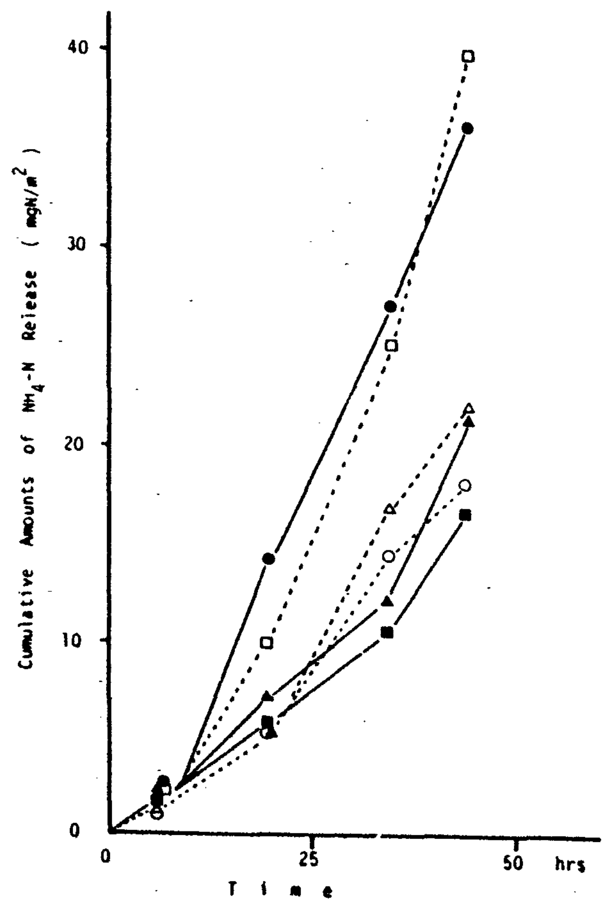

Figure 7. Cumulative amounts of NH_4-N release measured by the in-situ core method, August 17-19

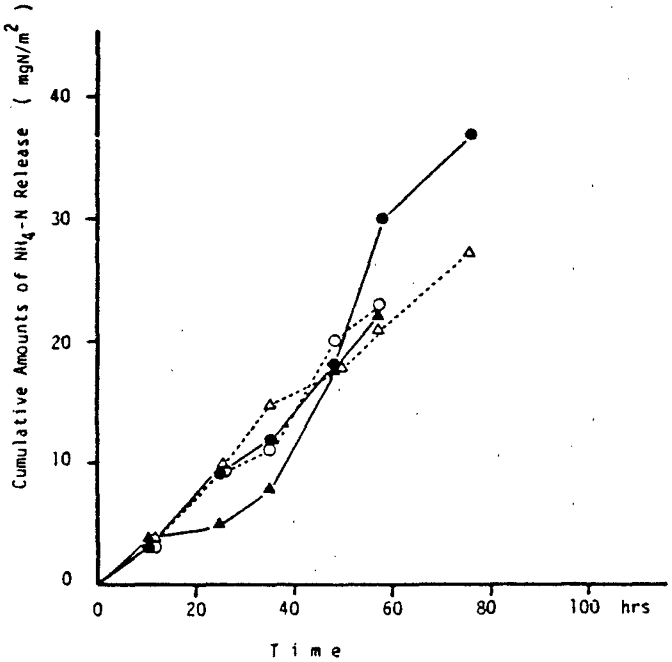

Figure 8. Cumulative amounts of NH_4-N release measured by the in-situ chamber method, August 17-21

Eleven cores were taken in the mathematical model method. Two sets of surface sediment layers were separated from the cores sampled to estimate NH_4-N concentration of interstitial water in the uppermost layer of the sediment, i.e. 6 and 5 cores were used to obtain layers of 1 cm thickness from the sediment surface (0-1 cm, Δl = 0.5 cm) and those of 2 cm thickness (0-2 cm, Δl = 1.0 cm), respectively. In this method t = 10°C of lake bottom temperature and ϕ = 0.95 measured from water content and density of sediment were used.

Table 2 shows the mean values, standard deviations, and coefficients of variation of NH_4-N flux evaluated from the laboratory core method, the in-situ core method, the in-situ chamber method, and the mathematical model method. The mean NH_4-N release rates evaluated from each method ranged between 9.6 mg N/m^2 day and 16 mg N/m^2 day. Similarly, the coefficients of variation ranged from 15% to 39%.

Next, the precision of the NH_4-N release rates determination among the five methods (shown in Table 2), including two kinds of mathematical model methods (Δl = 0.5 cm and Δl = 1.0 cm), was compared. Table 3 shows the results of statistical test on the differences of variances among the NH_4-N release rates. No significant difference ($P < 0.05$) of the variances was found between Δl = 0.5 cm and Δl = 1.0 cm in the mathematical model methods. There were no significant differences among the two mathematical model methods, the laboratory

Table 2. Mean values, standard deviations, and coefficients of variation of NH_4-N flux evaluated from the laboratory core method, the in-situ core method, the in-situ chamber method, and the mathematical model method

Methods	Determined values		
	Mean ($mg\ N/m^2/day$)	SD	%CV
Laboratory Core Method	11.5	1.76	15.3
In-situ Core Method	15.0	5.83	38.9
In-situ Chamber Method	9.6	1.55	16.1
Mathematical Model Method ($\Delta\ell$ = 0.5 cm)	15.7	3.04	19.4
Mathematical Model Method ($\Delta\ell$ = 1.0 cm)	13.2	2.94	22.2

Table 3. Results of statistical test on the differences of variances among the NH_4-N release rates determined by the laboratory core method, the in-situ core method, the in-situ chamber method, and the mathematical model method ($\Delta\ell$ = 0.5 cm and $\Delta\ell$ = 1.0 cm)

	Laboratory Core	In-situ Core	In-situ Chamber	Model ($\Delta\ell$ = 0.5 cm)	Model ($\Delta\ell$ = 1.0 cm)
Laboratory Core	____	X	NO	NO	NO
In-situ Core		____	X	NO	NO
In-situ Chamber			____	NO	NO
Model ($\Delta\ell$ = 0.5 cm)				____	NO
Model ($\Delta\ell$ = 1.0 cm)					____

X = Significant difference ($P < 0.05$)
NO = No significant difference ($P < 0.05$)

core method, and the in-situ chamber method. Significant difference ($P < 0.05$) existed between the in-situ core method and the laboratory core method, and between the in-situ core method and the in-situ chamber method. Accordingly, the in-situ core method reflected the least precision of the NH_4-N release rate determinations among the five methods as shown in Table 3. Results of the statistical test indicated that there was no difference among the precision of the NH_4-N release rates evaluated from the laboratory core method, the in-situ chamber method, and the mathematical model methods.

The differences of the mean values of NH_4-N release rates were examined for the methods where no significant difference among the variances was found. There was no significant difference ($P < 0.05$) between the mean values calculated from the mathematical model methods of $\Delta\ell = 0.5$ cm and $\Delta\ell = 1.0$ cm. The mean values calculated from the mathematical model method of $\Delta\ell = 0.5$ cm were significantly greater than those evaluated by the laboratory core method and the in-situ chamber method.

However, the mean values calculated from the mathematical model method of $\Delta\ell = 1.0$ cm were not significantly different from those evaluated from the laboratory core method and the in-situ chamber method.

These statistical tests showed that the NH_4-N release rates calculated from the mathematical model method of $\Delta\ell = 1.0$ cm did not differ from those estimated by the methods of measuring the cumulative amounts of NH_4-N released from sediment to overlying water. The mathematical model method, therefore, would be substituted for the other methods that require long time incubation.

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DREDGING AND MANAGEMENT PROBLEMS IN LAKE SUWA

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ABSTRACT

Dredging in Lake Suwa commenced in 1969 and is still in progress. The start of this dredging work was very early in the history of environmental improvement in our country. The first stage work, which aimed to remove sediment from shallow zones below 2.5 m, was finished in 1980. However, it brought about no remarkable improvement in water quality. These results were not surprising since the dredged area was only a small part of the lake.

In review of the results, a new project was established in 1981 to dredge the remaining deeper zones. The project began this year. This paper deals with the dredging and management problems of this new project.

BACKGROUND

Lake Suwa, located in Nagano Prefecture in the central part of Japan, is the 15th largest lake in our country and is 759 m above sea level.

It has a basin of 531.2 km^2, a lake area of 13.3 km^2, and a mean depth of 4.7 m. The lake is surrounded by urban areas including several cities such as Okaya, Suwa, Shimosuwa, and Chino. The total population is about 150,000. As this area is a famous hot spring zone, it has a large number of tourists in addition to the residents. It was natural that urban drainage would flow into the lake and cause serious pollution problems.

The COD concentrations in the lake water changed with time as shown in Figure 1. They increased gradually from 1960, and reached a maximum value of 10 ppm in 1973 and after that held constant between 6 ppm and 10 ppm.

The lake is designated as an A type body of water by the Environmental Agency, in which COD concentrations must be maintained below 3 ppm. The present state is over twice that. Lake pollution advanced so seriously that the lake suffers from a large crop of algal blooms in summer.

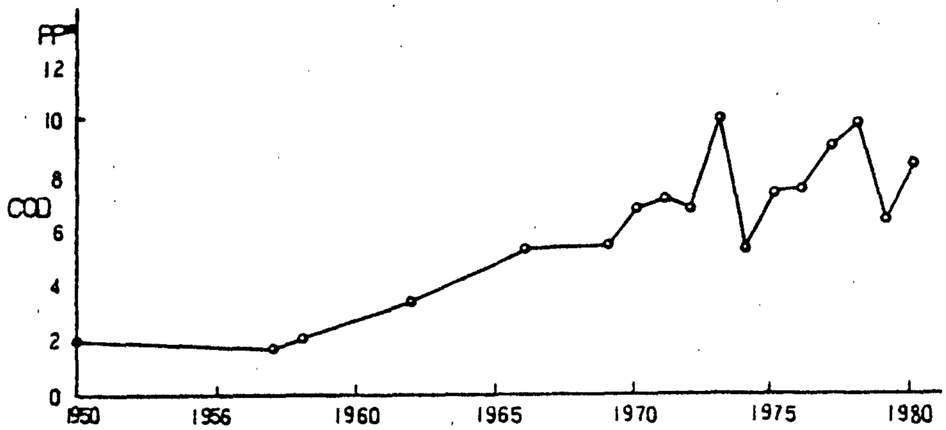

Figure 1. Variance of COD concentrations

SEDIMENT POLLUTION

In 1978 a sediment survey was conducted on a large scale as shown in Figure 2. Sediment samples were taken from 48 points.

The average nutrient concentrations in sediment surfaces were as follows:

T-P = 4100 mg/kg

T-N = 4920 mg/kg

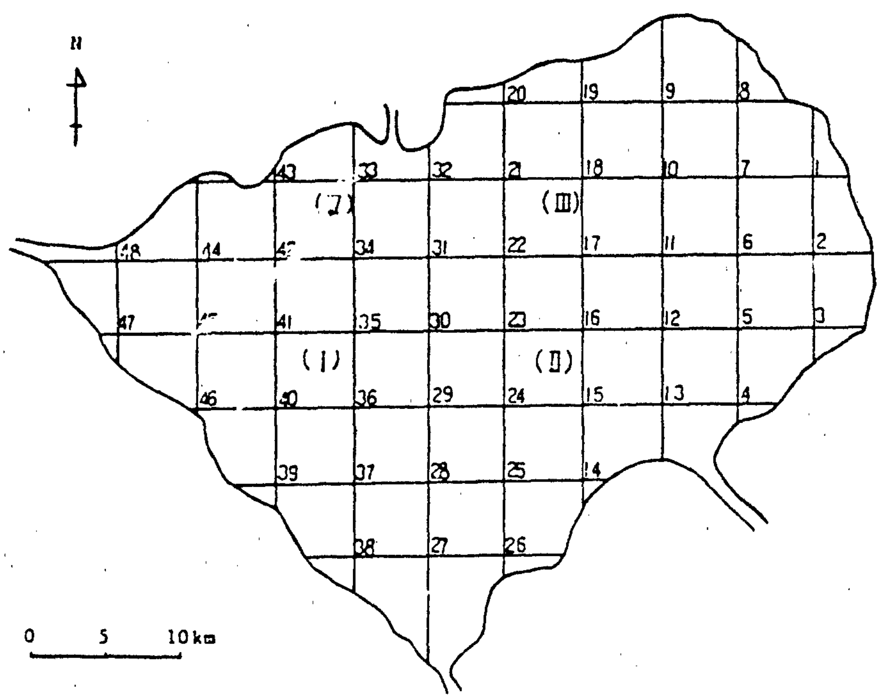

Figure 2. Sediment sampling conducted in 1978

Their maximum values were extremely high, indicating a large deviation as follows:

Max T-P = 35,000 mg/kg

Max T-N = 7,950 mg/kg

From these data, it was found that large quantities of nutrient material have accumulated on the lake bottom. It is likely that the release rates from sediment might also be great. This is demonstrated by release tests, which show that the release rates were 11.9 kg/m^2/day for T-P and 15.6 mg/m^2/day for T-N. These release materials generate a large peak in nutrient concentrations in summer, as Yoshida pointed out, and result in a large crop of microcystes.

DREDGING PROJECT

The dredging in Lake Suwa commenced in 1969 and is still in progress. The first stage of the dredging work removed sediment from shallow areas below 2.5 m (Figure 3). Completed in 1980, the total amount of dredged material equaled about 1,500,000 m^3.

This dredging had no significant effects for the following reasons:

a. The dredged area occupied only about 15% of the total area.

b. The majority of the polluting sediment is in the deeper zones, as Figure 4 shows.

c. The dredging rate was too small. It required 12 years to remove sediment that occupied only 15% of the whole area.

Considering these results, it was decided to dredge the deeper depths as the second stage work. Beginning in 1981, the total amount of sediment to be dredged was estimated at about 5,300,000 m^3. In view of the results up to now, the following conclusions are drawn:

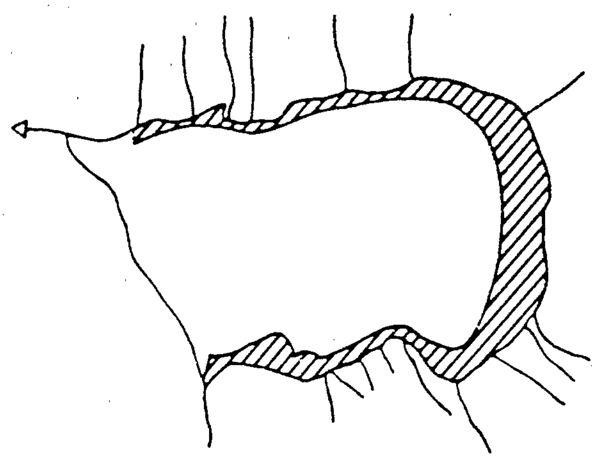

Figure 3. Dredged area in the first stage work

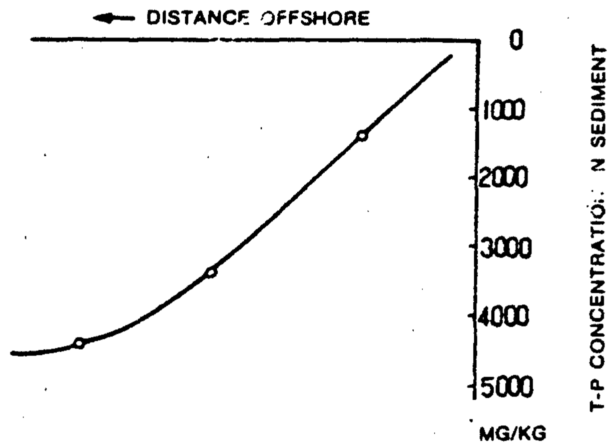

Figure 4. Sediment pollution
versus distance offshore

(a) The dredging should commence in the heavily polluted area. The area to dredged is divided into four blocks (Figure 5). The average nutrient concentration in sediment for each block is as follows:

	No. 1	No. 2	No. 3	No. 4
T-P mg/kg	7206	3225	3528	2439
T-N mg/kg	5611	4989	5402	3456

From this it can be seen that the 1st block is the heaviest in pollution and the 4th is the lightest. Consequently, the dredging sequence will be I → II → III → IV.

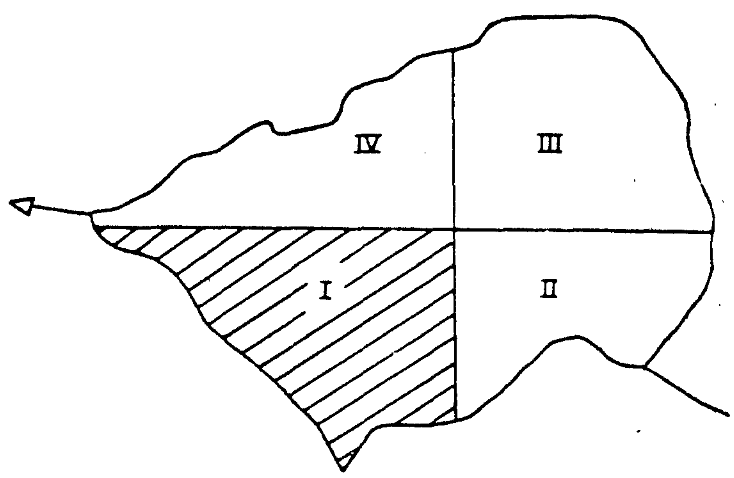

Figure 5. Four blocks of dredge area

(b) The work period will be 20 years. Although the shortest possible period is desirable, when considering the financial difficulty, 20 years is judged appropriate. The dredging rate of the second stage is much larger than that of the first stage.

The removal thickness of sediment was determined from the following:

(1) Vertical distribution of nutrient concentrations in sediment against sediment depth.

(2) Reduction of release rates by sediment removal.

(3) Reduction of sediment oxygen demand by sediment removal.

The relationships between release rates and removal thickness are shown in Figure 6. The lower the release rate, the thicker the removal thickness. However, the increment becomes smaller according to the removal thickness; the release rates decrease no further if the thickness is over 50 cm. From this, the removal thickness was set at 50 cm.

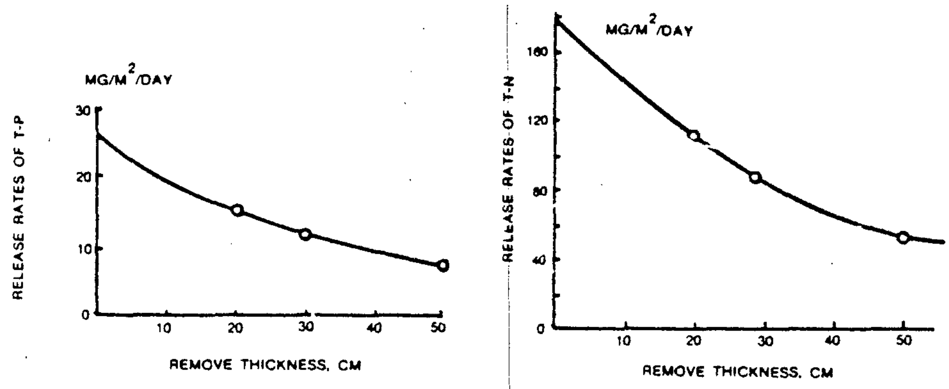

Figure 6. Relationship between release rates and removal thickness

MANAGEMENT OF DREDGED MATERIAL

In the second stage work, the most difficult problem is management of the dredged material. In the first stage work, the dredged material was used mostly for road banking (built around the lake at the similar time). Such a use is not feasible at this time since road building is nearly complete.

At Lake Suwa there is no space for disposing the dredged material due to the narrowness of the land surrounded by high mountains. Therefore, the dredged material has to be transported to other places, where it might be used for banking and other purposes. To do this, it is necessary to dewater the dredged material as quickly as possible at the lake side.

The dewatering methods may be classified in two ways: mechanical dehydration and in-pond sedimentation. To examine these two methods from the technical and economical view points, tests on mechanical dehydration were

conducted in 1981, and tests on dewatering by in-pond sedimentation were scheduled for 1982.

Mechanical Dehydration Tests In Situ

The dredged material was removed by a dredge with a 420 h.p. pump and transported hydraulically to a 7000-m^2 disposal pond (Figure 7).

The test was performed near the disposal pond. To promote sedimentation in the management pond, 45 ppm of inorganic flocculant (PAC) and 3-7 ppm of polymeric coagulant were added to the pipe at the pond entrance (Figure 8). A filter press was chosen to dewater the dredged material. The filter press has 30 chambers having an area of 0.9 m and a width of 117 cm. The flowchart of the test plant is shown in Figure 9. The layout of the dehydration test plant is indicated in Figure 10.

The tests were carried out in such a way that:

a. The densified slurry was pumped up from the management pond by a submerged sand pump and fed to the storage tank (27 m^3) and therein mixed uniformly by a sand pump with a mixer.

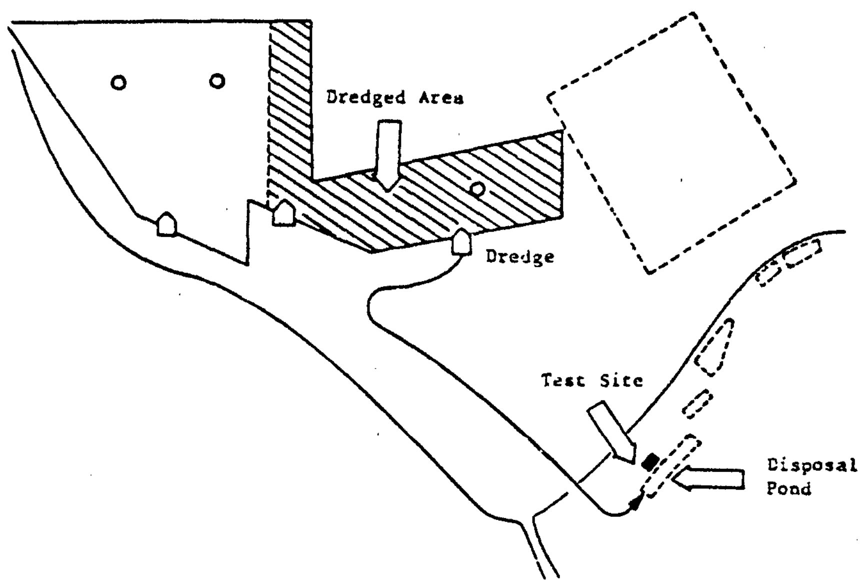

Figure 7. Disposal and test site

b. The homogeneous slurry was transported to the agent mixing tank (1.5 m^3). Gravel or wood chips were removed by a screen at the inlet to the tank.

c. A predetermined amount of flocculant was added to the slurry in the tank and agitated with an agitating vane, and was then transported to the slurry tank (6 m^3) set at the bottom.

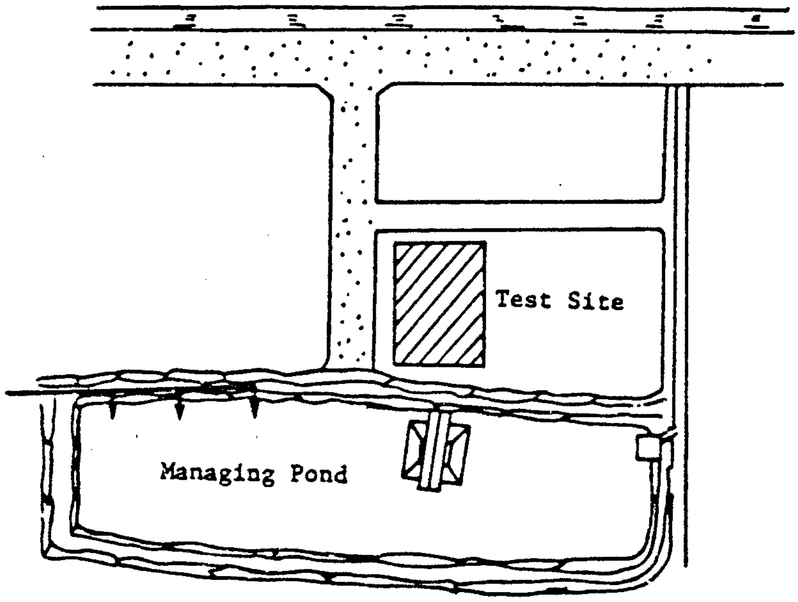

Figure 8. Management pond and test site

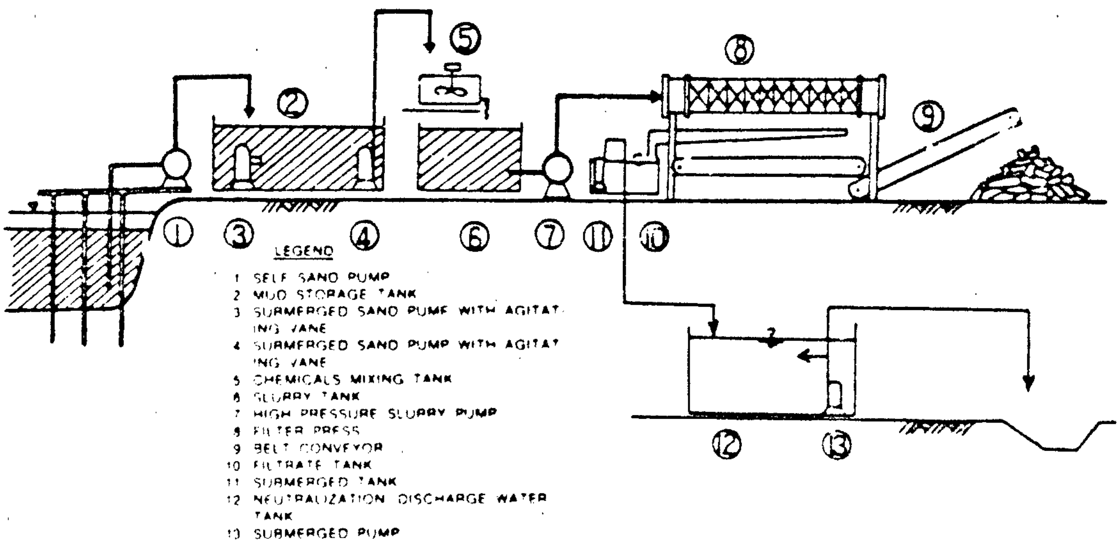

Figure 9. Flowchart of test apparatus

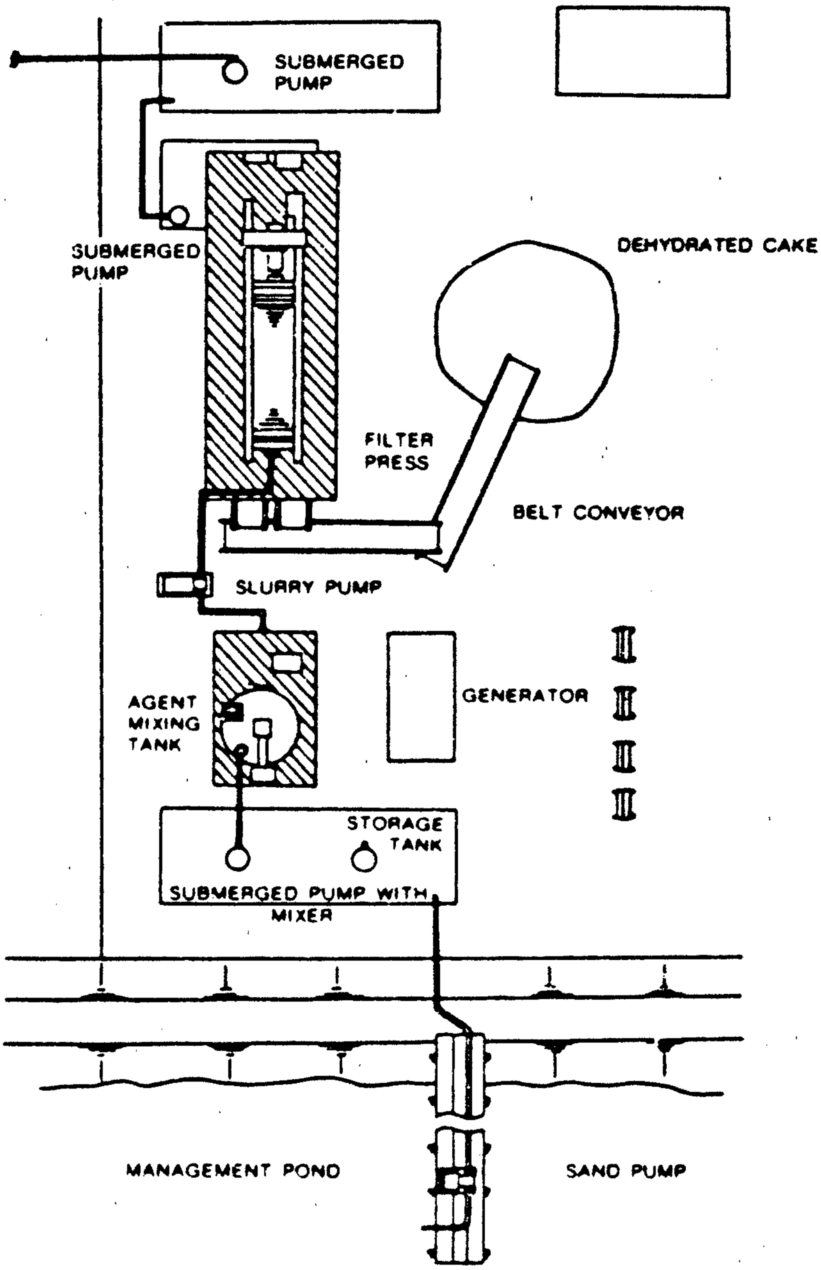

Figure 10. Layout of test plant

d. The coagulated slurry was drawn out from the tank bottom by a high pressure slurry pump, pressed into the filter press under pressure, and dehydrated at a pressure of 3-5 kg/cm^2. After the predetermined quantity of slurry was fed, the filter frame was opened and a dehydrated cake discharged.

e. The turbid filtrate which came out at the first stage of the dehydration process was returned to the settling pond. The clarified filtrate was stored in the neutralizing tank (22 m^3) and then discharged into the lake.

The test conditions were set as follows:

a. The specific gravity of the slurry pumped up from the management pond was adjusted to a range between 1.04-1.08.

b. Three kinds of flocculant were used: slaked lime, alum, and cement. The use of alum was expected to neutralize the dehydrated cake with the mixture of slaked lime. Their dosage was 1.0-10 kg/m^3 of slurry.

c. The feeding duration of slurry to the press was 20-135 min.

Test Results

Dehydrated Cake

The properties of the dehydrated cake are shown in Table 1.

Table 1. Cake Properties

Item	Unit	Slaked Lime	Slaked Lime and Alum
Water content	%	135-166	130-166
Unit weight	g/cm^3	1.30-1.34	1.28-1.32
pH		10.0-10.7	8.4-9.2
COD	mg/g	30.1-48.6	39.4-44.7
T-N	mg/g	4.6-5.5	4.3-5.3
T-P	mg/g	2.1-2.2	2.0-2.2
Cu	mg/kg	1.2-2.9	1.8-4.0
As	mg/kg	3.8-5.0	2.2-4.3

The difference between single (slaked lime) and mixed coagulants (slaked lime and alum) appeared in the pH values, with the latter indicating the lower values of pH.

Filtrate

The properties of filtrates are shown in Table 2.

Table 2. Filtrate Properties

Item	Unit	Only Slaked Lime	Slaked Lime and Alum Mixed
pH		10.4-11.4	7.6-9.4
SS	mg/ℓ	14.0-17.4	6.0-17.0
Turbidity	degr.	5-9	1-8
COD	mg/ℓ	19.3-22.7	6.4-12.5
T-N.	mg/ℓ	5.0-7.0	2.6-3.5
T-P	mg/ℓ	0.25-0.30	0.06-0.15

The use of mixed coagulants gave good results for every item and is recommended over slaked lime.

Relationship Between Filtration Rates and Coagulant Dosage

The filtration capacity is normally represented in terms of filtration rate, which denotes the quantities of the dehydrated cake per unit of filtration area and unit time. From the test results, it is found that the filtration rates depend upon the specific gravity of the slurry, kinds of coagulant, and water content of the cake. The test results are summarized in Figure 11.

As Figure 11 shows, the higher the coagulant dosage, the higher the filtration rate. However, the filtration rate stops increasing beyond a certain point.

From these data, we can say that an appropriate filtration capacity for lake sediment in Suwa is 4.75 kg/m^2/hr of dredged sediments.

CONCLUSIONS

The tests results are summarized in Table 3.

The tests verified the applicability of mechanical dehydration to sediment dewatering. The most advantageous points of the mechanical dehydrator are (1) minimal water content of the cake, (2) minimal treatment time, and (3) minimal space requirements.

These points apply to the conditions at Suwa Lake since there is no place for disposal. However, it is presumed that the only disadvantage of the mechanical dehydrator may be the high cost of operation and equipment. To study this problem, tests on dewatering by in-pond sedimentation are scheduled to be conducted in 1982. The technical and economical comparison between them will be examined upon test completion.

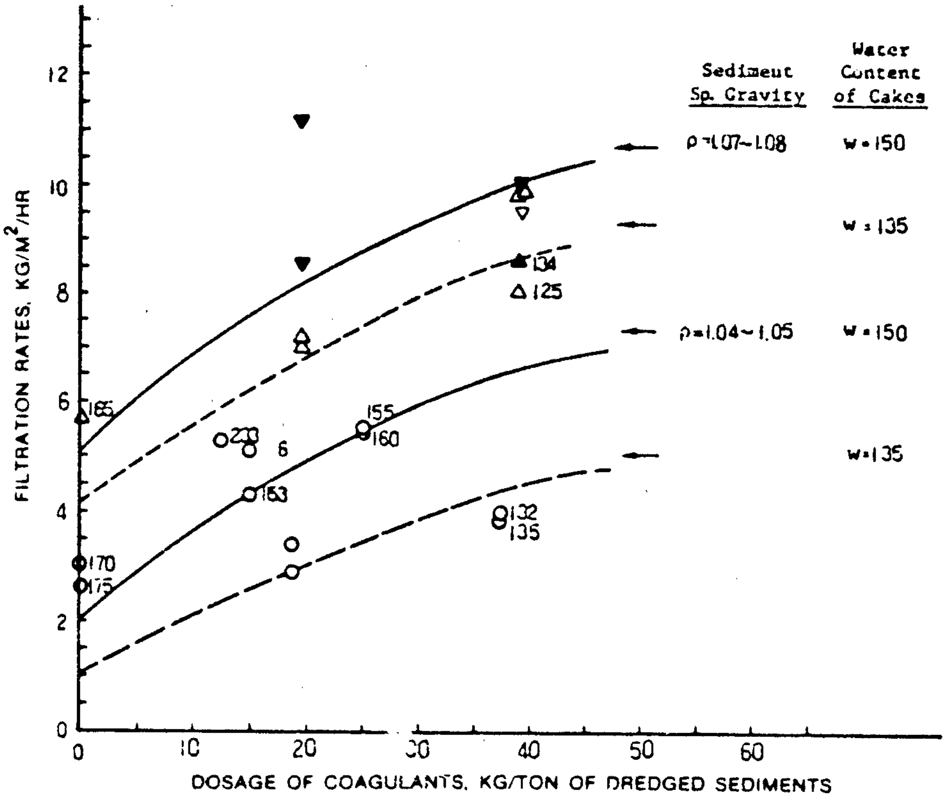

Figure 11. Relationship between filtration rates and dosage of coagulants

Table 3. Results of Mechanical Dehydration Tests

Dredged Slurry	Dosage of Coagulants per ton of Dredged Sediments	Dehydrated Cake	Filtrate
(1) Density 1.04-1.05 t/m^3	(1) Slaked lime 12.5 kg (average 0.9 kg/m^3 slurry)	(1) Water content 150%	(1) pH 7-8.6
(2) Solid concentrations 64-80 kg/m^3	(2) Alum 12.5 kg (average 0.9 kg/m^3 slurry)	(2) Wet unit weight 1.330 t/m^3	(2) SS < 50 mg/ℓ
		(3) Compressive strength 0.5 kg/cm^2	(3) COD < 20 mg/ℓ
		(4) Cone penetrator depth 1 m/m	(4) T-N < 5 mg/ℓ
			(5) T-P < 92 mg/ℓ

EMERGENCY RESPONSE EQUIPMENT TO CLEAN UP HAZARDOUS CHEMICAL RELEASES AT SPILLS AND UNCONTROLLED WASTE SITES

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ABSTRACT

This paper reviews some of the research activities of the U.S. Environmental Protection Agency (EPA) regarding the development of emergency response equipment to control hazardous chemical releases. Several devices and systems have been developed by EPA for environmental emergencies involving spills and uncontrolled waste sites. Many of these have already been made available commercially by industry, including a mobile physical/chemical treatment system for processing contaminated water at hazardous incidents and a mobile laboratory for onsite chemical analyses. Other operationally ready devices addressed in this paper include: a mobile stream diversion system for isolating segments of small streams to facilitate the removal of contaminated sediments; a portable back-pack polyurethane foam diking system for the containment of spilled chemicals; and an acoustic emission-based spill alert device for detecting imminent dike failure at lagoons containing toxic and hazardous wastes. Prototypical equipment, described in this paper, which are now undergoing shakedown testing and evaluation include: a mobile soils washing system for extracting spilled materials from excavated soils onsite; and a mobile, field-use incineration system for the thermal destruction of toxic organic compounds.

INTRODUCTION

Problem

Billions of metric tons of oils and hazardous chemicals are produced and handled annually in the United States. These materials range from gasoline and fuel oils, to vegetable oils, sulfuric acid, lye, chlorine and chlorinated compounds, cyanides and isocyanates, and include hundreds of millions of kilograms of toxic pesticides and pharmaceuticals. Millions of metric tons

are released into the water, land, and air environment each year--often with catastrophic consequences--due to spills resulting from ship, truck, and train accidents, equipment malfunction, transfer line failure, broken pipelines, lagoon dike rupture, overfilling, leaking storage tanks, container puncture, flood, earthquake, fire, and explosion.

Similarly, millions of metric tons of hazardous wastes are generated in this country each year from manufacturing, processing, and other industrial operations. Disposal of this substantive quantity of waste is a matter of great public concern in the wake of numerous case histories involving negligent dumping practices resulting in several instances of contamination that have severely damaged the environment and threatened human life. Perhaps the most dramatic example of inadequate disposal of hazardous chemical wastes occurred near Niagara Falls, New York, where hundreds of families living along an abandoned waste disposal site, known as Love Canal, had to permanently evacuate their homes when the toxic chemicals migrated from the site and seeped through the ground into their basements.

Legislative Background

The U.S. Congress addressed the problem of oil and hazardous material spills in Public Law 95-217, the Clean Water Act (CWA) of 1977, and its predecessor statute, Public Law 92-500, the Water Quality Improvement Act of 1972, which authorizes the Federal Government to take emergency response action when oils and specially designated hazardous substances are discharged into navigable waters (1). These statutes, however, are seriously limited in their authority to deal with the variety of problems caused by releases of hazardous substances onto land or into groundwater and air.

Public Law 94-580, the Resource Conservation and Recovery Act (RCRA) of 1976, was the first comprehensive Federal legislation to deal with the hazardous waste issue. RCRA establishes a regulatory system to track hazardous wastes from the time of generation to disposal. It requires safe and secure procedures to be used in treating, storing, and disposing of hazardous wastes and is designed to prevent the creation of new Love Canals in the future. RCRA, however, does not permit the government to respond directly to the problems caused by improper (uncontrolled) hazardous waste disposal sites already in existence.

Legal authority to overcome the limitations of both CWA and RCRA was provided in 1980 by the enactment of Public Law 96-510, the Comprehensive Environmental Response, Compensation, and Liability Act (commonly known as Superfund) (2) which authorizes Federal emergency response to <u>any</u> hazardous substance release into the environment which endangers public health and welfare--including the cleanup of uncontrolled hazardous waste sites and the mitigation of spills not only in navigable waters, but also in groundwaters, soils, sediments, and the atmosphere.

RESEARCH AND DEVELOPMENT

Successful implementation of the Superfund legislation, as well as the Clean Water Act and the Resource Conservation and Recovery Act, requires major

research and development efforts. Controlling and cleaning up hazardous substances is a relatively complex field. Specialized equipment and techniques are needed in order to respond quickly and effectively to emergencies and to dispose of the materials in an environmentally safe manner. Both industry and the government are working diligently to learn more about controlling these materials and to develop appropriate cleanup devices and equipment. Within the U.S. Environmental Protection Agency (EPA), the Municipal Environmental Research Laboratory (MERL) has the lead role for research and development related to hazardous waste environmental emergencies. Through a program at its Oil and Hazardous Materials Spills Branch in Edison, New Jersey, MERL is developing prototypical equipment and experimental techniques for the prevention, control, and abatement of multi-media pollution from hazardous chemical spills and mismanaged hazardous waste disposal sites.

The main thrust of the program centers around emergency response research to develop the tools to remove the immediate threat of a hazardous material

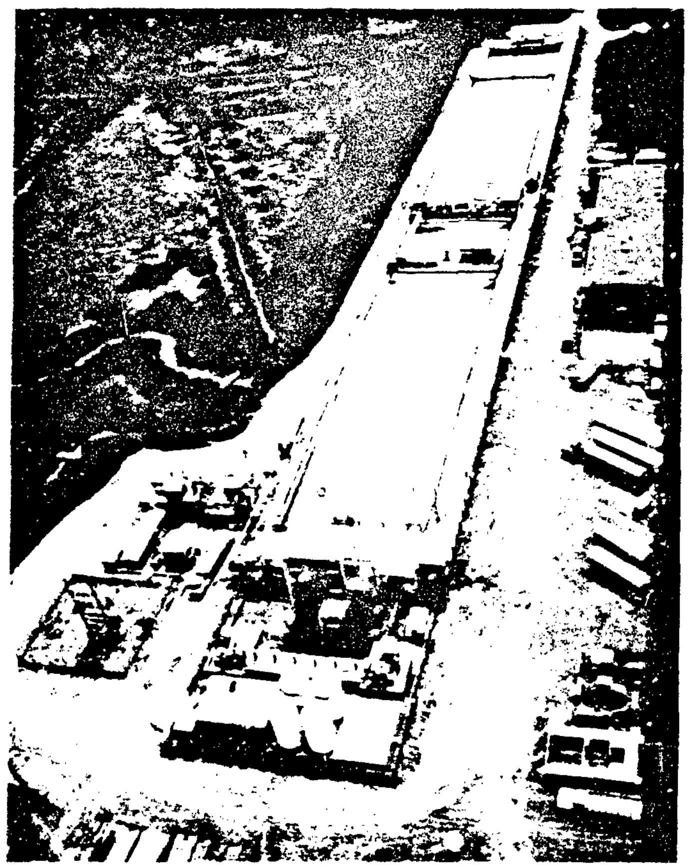

Figure 1. Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT), the world's largest facility for the environmentally safe testing of spill cleanup methods and technologies.

incident in order to control the emergency and protect human health and the environment. A major testing facility of the program is the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT), which consists chiefly of a 9.8 million liter (2.6 million gallon) concrete tank with mobile bridges, a wave generator, and a simulated beach (Figure 1). OHMSETT is the only facility in the world of its kind for the testing, evaluation, and development of full-scale spill cleanup equipment, devices, and systems under controlled, environmentally safe and reproducible conditions (3,4).

Development of hardware and techniques is carried out from the concept stage through the prototype stage to field testing and demonstration. A major objective of the program is to demonstrate the applicability of the prototypical equipment at spills and waste sites throughout the country, thereby stimulating the commercial adoption or adaptation of the devices and encouraging private firms to manufacture or use similar equipment.

Equipment or Systems Currently Field Ready

Several prototypical emergency response devices have been developed, tested, evaluated, and demonstrated to the point where they are fully operational (5). Examples of some of these field-ready devices follow:

Mobile Physical/Chemical Treatment System

This device (Figure 2) is designed to remove hazardous chemicals from water by a variety of physical/chemical treatment steps employed in the

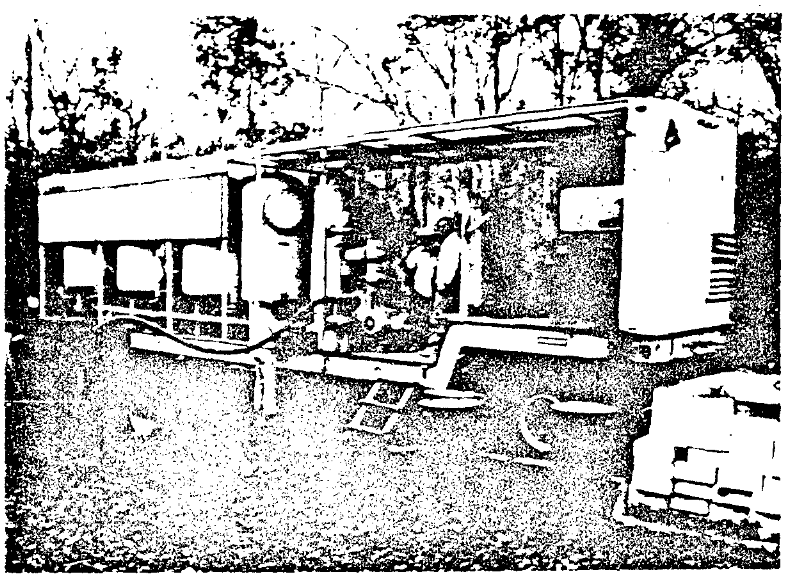

Figure 2. Mobile physical/chemical treatment system for processing contaminated water.

field. It contains equipment for coagulating and settling suspended solids, filtering very fine particulates, and adsorbing dissolved organic contaminents using granular activated carbon. Mounted on a 13.7-m (45-ft) drop deck trailer, the system (6) incorporates three mixed-media filters, three pressure carbon columns (which may be used in parallel or in series), pumps, piping controls, and a 100-KW diesel generator. A support trailer is equipped with additional pumps and several collapsible rubber tanks which serve as sedimentation, chemical reaction, and storage containers. Contaminated water can be processed at flow rates between 379 and 2270 liters (100 to 600 gallons) per minute. The system has been used at more than 30 cleanups of uncontrolled hazardous waste sites and spills of hazardous materials around the country. Commercial units patterned after the EPA system are now routinely employed.

Mobile Decontamination Station

This 12.2-m (40-ft) trailer (Figure 3) is engineered to provide onsite safety support for emergency response personnel. It is intended to ensure that exposed personnel do not leave the site without a proper washdown and clothing change. The unit is placed at the boundary of a cleanup site, and all personnel are required to pass through it when entering and leaving the site. The trailer is divided into three compartments: [1] a "clean" room with lockers for storing street clothing; [2] a shower room; and [3] a "contaminated" room with lockers for work clothing. This room also includes a clothes washer and dryer. The decontamination station is equipped with a freshwater supply and holding tanks for wastewater which must be processed prior to discharge. The unit has already been used in the field in support of cleanup activities, and has been duplicated by a commercial spill cleanup contractor.

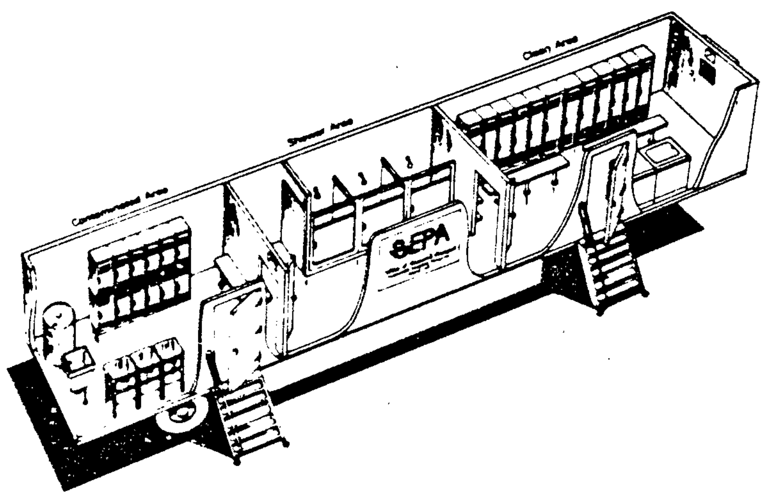

Figure 3. Mobile decontamination station for use of field personnel at cleanup activities involving toxic materials.

Mobile Laboratory

This unit, contained within a 10.7-m (35-ft) semi-trailer (Figure 4), is designed to provide analytical services during the cleanup of hazardous materials at spills and uncontrolled waste sites (7). Having analytical capabilities at the field site avoids delays inherent in shipping samples to a central laboratory. The mobile laboratory contains a broad range of sophisticated instrumentation, including a gas chromatograph/mass spectrometer (GC/MS), computerized gas chromatographs, an atomic absorption spectrometer, infrared and fluorescence spectrometers, and other highly sensitive analytical tools. Special sample processing techniques and glove boxes permit safe handling of high concentrations of toxic chemicals. During the past few years, the mobile laboratory has been used to perform several thousand sample analyses in a variety of emergency response situations. The laboratory has been used as a model by a number of spill cleanup contractors who have built similar mobile units for commercial application.

Figure 4. Mobile laboratory to provide analytical services at emergency incidents involving hazardous chemicals.

Acoustic Emission Monitoring Device

This device (Figure 5) is designed to provide an early warning of potential failure to earthen dams containing hazardous materials (8). Earthen dam ponds can be found at almost any hazardous waste site in the United States. Many of these impoundments are unstable and, with slight overstressing (such as from heavy rains), may collapse and spill their contents into the environment with potentially drastic consequences. The acoustic emission monitoring device detects instability in earthen dikes by measuring noises generated by soil particle movement. The intensity and frequency of these sounds (acoustic emissions) have been correlated with stress levels for various soils and,

therefore, can be used to indicate stability of dike structures. Acoustic emissions are transmitted to the surface of the dike through metal rods (waveguides) inserted into the impoundment wall. These sounds are converted to electrical signals which are amplified and recorded for analyses. The device, which has been commercialized in at least three versions, has received wide recognition as a simple, portable, inexpensive tool for assessing impoundment stability and preventing spills.

Figure 5. Acoustic emission monitoring device for detecting imminent dike failure at lagoons containing toxic and hazardous wastes.

Foam Dike System

This system (Figure 6) is designed to provide a rapid response method for containing or diverting the flow of many spilled hazardous chemicals (9,10). The diking unit consists of an 18-kg (40-lb) back-pack device that generates approximately 0.8 m^3 (30 ft^3) of two-component, very rapid set-up polyurethane foam. Larger sized commercially available units are capable of delivering 1.8 m^3 (65 ft^3) of foam which provides sufficient material to construct a barrier 0.3 m (1 ft) high by 0.3 m (1 ft) wide by 6 m (20 ft) in diameter,

which could impound approximately 7570 liters (2000 gallons) of spilled hazardous liquid. The polyurethane foam adheres well to most dry surfaces (pavement, earth, etc.) for making stable dikes, and can also be used to plug storm drains on streets to prevent spilled hazardous materials from entering sewer systems. The diking unit has been designed as a compact, portable device to be carried by individual operators such as truck drivers or railroad train personnel. Several fire departments in this country have already used the foam diking system in emergency response operations involving hazardous substance releases.

Figure 6. Foam dike system for the emergency containment of spilled hazardous chemicals.

Mobile Stream Diversion System

The system (Figure 7) is intended to isolate segments of small streams so that contaminated sediments can be removed easily with mechanical earthmoving equipment (11). This approach is an alternative to dredging which typically requires extensive water treatment to remove contaminants that become suspended or dissolved during the pumping operation. Dredging also often leads to the downstream spread of the contaminant as a result of resuspension of bottom muds and silts. Isolation of a contaminated stream is accomplished by damming the stream above the impacted area and bypassing the normal stream flow. The stream diversion technique permits the spill-impacted segment to dry, thus facilitating mechanical cleanup. The major components of the system are booster pumps, submersible pumps, generators, a crane, and aluminum irrigation pipe. The system is designed to bypass the flow (up to 0.37 m^3/s [13 ft^3/s]) of a small stream for distances up to 914 m (3000 ft). An alternative use of the mobile stream diversion system is to divert or reroute surface runoff water around a highly contaminated hazardous waste site and prevent the spread of contamination to areas down gradient of the site.

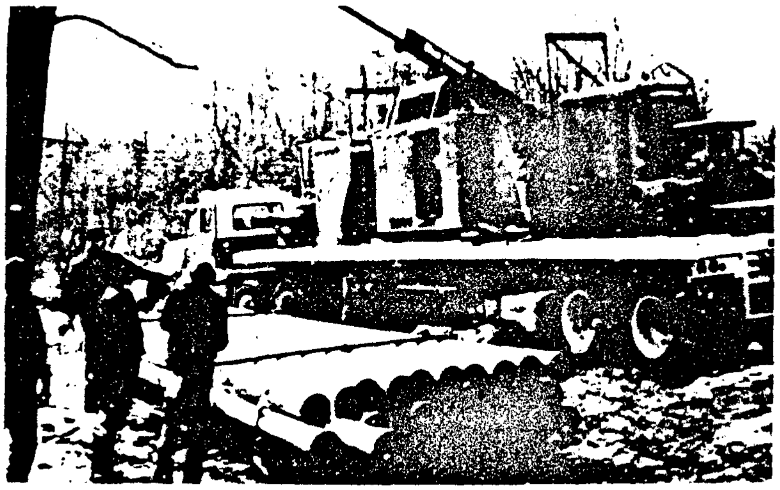

Figure 7. Mobile stream diversion system for isolating segments of small streams to facilitate the removal of contaminated sediments.

Hazardous Materials Spill Warning System

This in-stream system (12), which is capable of detecting a variety of spilled hazardous materials in waterways, is housed in an air-conditioned

Figure 8. Hazardous materials spill warning system for the continuous in-stream detection of a broad variety of spilled hazardous chemicals in water.

8.2-m (27-ft) automotive trailer (Figure 8). The system operates continuously at an unattended station, without maintenance, for a period of 14 days. A submersible pump in the watercourse supplies uninterrupted water samples to instrument consoles in the trailer. The consoles contain the following: [1] pH, electrical conductivity, and oxidation-reduction potential sensors for the detection of acids and bases, ionic compounds, and oxidizing and reducing substances, respectively; [2] a total organic carbon analyzer with a built-in recorder for the detection of organic compounds; [3] a differential ultraviolet absorptimeter for the detection of aromatic compounds; and [4] a control console with strip chart recorders. The hazardous materials spill warning system has already been demonstrated in the field to monitor discharges from uncontrolled hazardous waste sites.

Equipment or Systems Currently Under Test and Evaluation

A number of prototypical emergency response systems are now undergoing final shakedown testing and evaluation prior to full-scale field trials. Examples of some of these systems follow:

Mobile Incineration System

This system (13) was developed for field use to destroy hazardous organic substances collected from cleanup operations at spills and uncontrolled hazardous waste sites. The unit is designed to EPA's PCB destruction specifications (under Public Law 94-469, the Toxic Substances Control Act of 1976) to provide state-of-the-art thermal detoxification of long-lived, refractory organic compounds. Hazardous substances that can be incinerated, for example, include compounds containing chlorine and phosphorus (such as PCB's, kepone, dioxins, and organophosphate pesticides) which may be in pure form, in solution, in sludges, or in soils.

The mobile incinerator consists of four over-the-road trailers (Figure 9) with specialized combustion equipment, air pollution control devices, and monitoring instrumentation. Organic wastes are fully vaporized and completely or partially oxidized at 982°C (1800°F) in a refractory-lined rotary kiln. Off-gases are passed through a secondary combustion chamber at 1204°C (2200°F) where thermal decomposition of the contaminants is completed. Acid gases and particulates generated by the combustion process are removed in the system's sophisticated air pollution control apparatus. A comprehensive monitoring system is used to analyze the flue and stack gases for combustion and emission components and is designed to automatically halt the feeding of waste to the incinerator if gas emissions exceed acceptable levels. Design processing rates for the incinerator are 4080 kg/hr (9000 lb/hr) of contaminated dry sand, or 680 kg/hr (1500 lb/hr) of contaminated water, or 284 l/hr (75 gal/hr) of contaminated fuel oil.

A series of test burns with fuel oil has already been completed. In order to systematically evaluate the equipment, PCB trial burns are currently under way. These trials are intended to demonstrate the incinerator's ability to meet or exceed the performance requirements established by Federal, State, and municipal regulations. After the trials, the system will be demonstrated at several hazardous waste sites around the country.

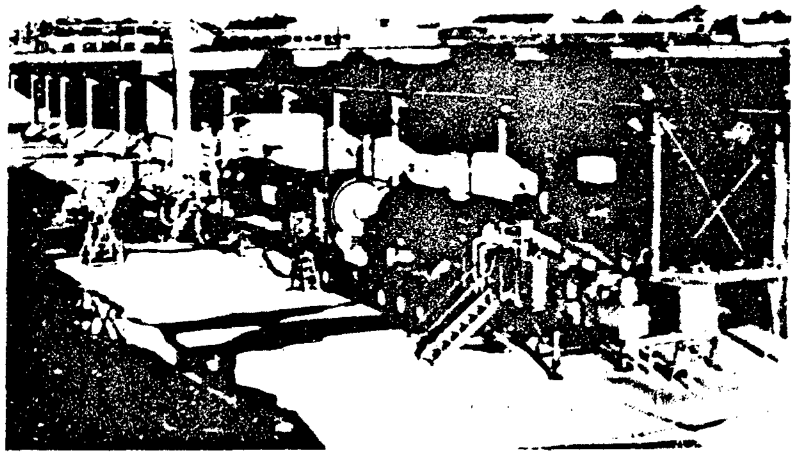

Figure 9. Mobile incineration system for the onsite destruction of refractory organic compounds.

Mobile Carbon Regeneration System

Waters contaminated with hazardous substances can now be cleaned with water purification equipment such as the EPA mobile physical/chemical treatment system (discussed above). Systems of this nature, which utilize granular activated carbon to adsorb the organic contaminants from the water, can be made more cost-effective with onsite regeneration of the spent carbon--thereby eliminating the problems associated with the transportation of contaminated carbon to a secure landfill or an offsite regeneration facility.

The mobile carbon regeneration system (Figure 10) provides a safe and effective method for detoxifying/regenerating contaminated carbon at the cleanup site. The system (14), mounted on a 13.7-m (45-ft) semi-trailer, contains a rotary kiln that heats the carbon in a slightly reducing atmosphere to about 982°C (1800°F) and releases the adsorbed contaminants as a vapor. (The atmosphere in the kiln is conditioned with water to enhance reactivation of the carbon.) The vapor passes into a secondary combustion chamber where it is totally decomposed. The flue gases are quenched with water sprays and scrubbed with alkaline solution to neutralize acids and remove particulates before venting to the atmosphere. Once the carbon is cooled with water, it is ready for reuse. The design processing rate for the carbon regenerator is 45.4 kg/hr (100 lb/hr) of dry granular activated carbon with 90% of the carbon's adsorption capacity restored after regeneration.

The mobile carbon regeneration system is now undergoing comprehensive shakedown testing and evaluation, and is expected to be ready for field demonstration during 1983.

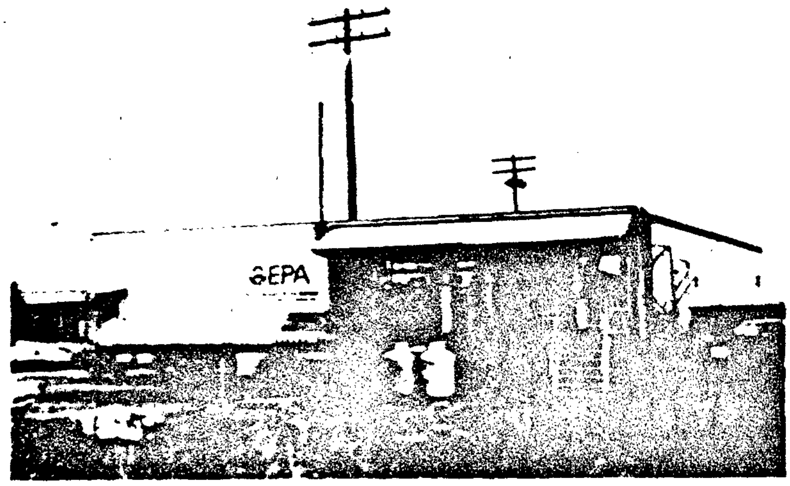

Figure 10. Mobile carbon regeneration system for field use in reactivating spent granular activated carbon used in spill or waste site cleanup operations.

Mobile Soils Washing System

This system (currently under development) is being designed for onsite removal of a broad range of hazardous materials from excavated soils (15). The soils washer is expected to be an economical alternative to the current practice of hauling contaminated soils offsite to a landfill, and replacing the excavated volume with fresh soil onsite. The system will be capable of extracting contaminants from soils--"artificially leaching" the soil using a water-based cleaning agent--and thereby enabling operators to leave the treated soil onsite. To accomplish this, the soil is passed through a rotating drum screen water knife soil scrubber where soil lumps are broken apart by intense jets of water, and chemicals are stripped from soil particles. The resulting soil slurry is fed into a 4-stage counter-current chemical extractor (similar to Figure 11). Each stage consists of a mixing, froth-flotation cell connected in series with hydrocyclones which centrifugally separate solids from liquids. The soil particles are agitated repeatedly in washing fluid and are progressively decontaminated as they flow through each stage. The cleansed soil is then returned to the site. The extracted hazardous contaminants are separated from the washing fluid using physical/chemical treatment procedures (flocculation, sedimentation, carbon adsorption, etc.). The cleaned washing fluid is recirculated while the separated and concentrated contaminants are disposed of by appropriate means.

The prototype soils washing system will be capable of processing 3 to 14 m^3 (4 to 18 yd^3) of contaminated soil per hour, depending on the soil particle size and the nature of the contaminant. The device is expected to be ready for shakedown testing and field trials in 1983.

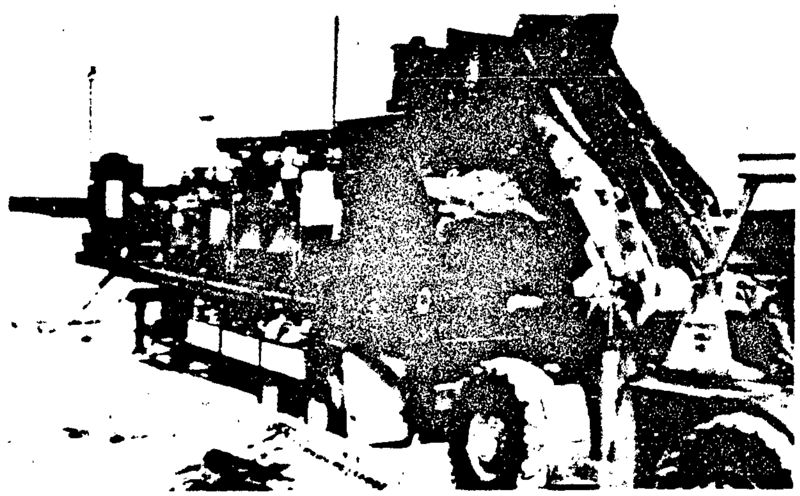

Figure 11. Chemical extractor for separating spilled materials from excavated soils onsite.

Mobile In Situ Soils Treatment System

Where large volumes of subsurface soils are contaminated at spills or hazardous waste sites, excavation of the soil is not economically feasible. A commercially available alternative approach is to flush the soil in place with water. The mobile in situ soils treatment system (16) offers an innovative, improved technique for treating contaminated subsurface soils in place at reduced costs, in terms of dollars per kilogram of contaminant removed. The technique employs water flushing with additives, and detoxification by chemical reaction.

The system (Figure 12) is mounted on a 13.1-m (43-ft) drop deck trailer and consists mainly of mixing, piping, and pumping equipment. In situ containment can be accomplished with this system through direct injection of grouting material into the soil around the contaminated area, thereby isolating the area. The contaminants are then treated in place by water-flushing with additives or by other methods such as oxidation/reduction, neutralization, or precipitation. Specially prepared solutions of wash water can be delivered into highly contaminated soil through 16 injectors (slotted or perforated pipes which are inserted into a series of holes drilled into the impacted area). A vacuum well point withdrawal system creates an artificial hydraulic gradient which draws the wash solution from the injectors through

the contaminated soil thereby speeding up the natural groundwater leaching process. The now chemically contaminated wash solution is processed through a mobile water treatment unit where contaminants are removed. Chemical additives are then introduced into the cleansed wash solution which is reinjected into the contaminated area for further treatment.

Preliminary testing of the mobile in situ soils treatment system has been completed and shakedown testing is now under way. The unit is scheduled for field evaluation in 1983.

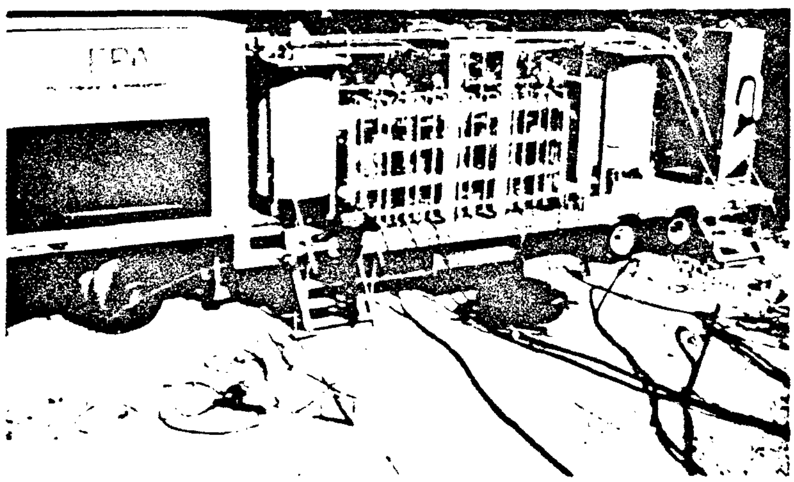

Figure 12. Mobile in situ soils treatment system for cleaning and detoxifying subsurface contaminatetd soils in place by water-flushing with additives, or by chemical reaction.

Other Technologies

The devices described in the preceding paragraphs are but a few of the items of emergency response hardware developed under the EPA Oil and Hazardous Materials Spills (OHMS) Branch research program. Other outputs of the program worthy of mention include the following:

- A trailer-mounted multi-purpose gelling agent system for solidifying and immobilizing spilled hazardous liquids and preventing their penetration through the soil into groundwater supplies (17,18).

- A pallet-mounted emergency collection bag and pumping system, consisting of a 26,500-liter (7000-gallon) furled Teflon-coated urethane bag and battery-powered or explosion-proof gasoline motor-driven pumps, for temporarily storing spilled hazardous chemicals (10).

- Portable field kits for use by spill response personnel to detect and identify a wide variety of spilled chemicals in water bodies (19,20).

- Enzyme-based systems for detecting the presence of spilled organophosphate and carbamate pesticides in water (21,22,23).

- A cyclic colorimeter--a device capable of performing opacity-sensitive determinations for the detection of spilled heavy metals in water (24).

- A field test kit for screening the contents of chemical waste drums at uncontrolled disposal sites for the presence of strong oxidizing and reducing agents (25).

- An ultrasonic device for locating sunken insoluble hazardous materials on the bottoms of water bodies (26).

- A computerized file of case history information which documents past field experiences of actual hazardous material incidents and provides easy retrieval of lessons learned (27).

CONCLUDING REMARKS

The development of effective emergency response technologies to control hazardous chemical releases at spills or waste sites is critical to EPA's mission to guarantee the protection of public health and the environment from the adverse effects of such chemical releases. A point has now been reached where several devices have been designed, constructed, and field tested. More will soon be available for actual use. As new equipment is developed, the OHMS Branch will continue to (a) conduct comprehensive shakedown testing to ensure field readiness and reliable performance on a rapid response basis; (b) conduct field trials to demonstrate operational capability and usefulness of the equipment in "real world" emergency situations; and (c) actively encourage commercialization of the new technology by making detailed plans, specifications, and design drawings available to the private sector.

Although the OHMS Branch research program is predominantly hardware oriented, its outputs also consist of technical reports, handbooks, guidance documents, and user manuals on a variety of emergency response-related areas including: protocols for ensuring personnel safety at waste sites and spills; practices for reducing the frequency and severity of spills; techniques for halting the release and spread of contamination to the surrounding water, air, soil, and sediments; methods for congealing spilled hazardous liquids and contents of damaged drums; procedures for characterizing the extent of hazardous material releases and for locating subsurface spills; techniques for controlling spillage from impoundments and waste lagoons; methodology for determining cleanup priorities and for evaluating alternative removal techniques; strategies for emergency contingency planning; methods for onsite encapsulation or destruction of hazardous substances recovered at spills or waste sites; and rapid emergency procedures for chemical analyses aboard mobile laboratories.

The technology developed under this program is transferred to the general public via the above documents as well as the biennial National Conferences

on Control of Hazardous Material Spills. EPA takes a lead role in organizing and promoting these conferences which are co-sponsored by other Federal agencies and private industrial organizations such as the U.S. Coast Guard and the Chemical Manufacturers Association, respectively. The Proceedings of these conferences are an excellent means of communicating the developments of the EPA emergency response research program to the user community (28-33).

DISCLAIMER

This paper has been reviewed by the Municipal Environmental Research Laboratory - Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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LEGAL RESTRICTIONS AND PRESENT CONDITION OF DREDGED MATERIAL DISPOSAL IN JAPAN

Atsushi Sugiyama

INTRODUCTION

At the previous meeting, the U.S. delegates presented several papers on the increasing difficulty in dredged material disposal and new techniques for the solutions. The PIANC and other agencies proposed that the regulations of the London Dumping Convention (LDC) concerning disposal control be reviewed.

In Japan, however, no problem has arisen from the implementation of dredging under the restrictions placed by the L.D.C. and relating domestic laws. Legal restrictions and the present condition of dredged material disposal in Japan are outlined in the following sections.

LEGAL RESTRICTIONS

When dredged material produced by port works is dumped into reclamation sites or the sea, dumping is controlled by the Law relating to the Prevention of Marine Pollution and Maritime Disasters (see Figure 1).

Prior to dredging, the material to be dredged is classified into the following three categories based on the results of the legally obligated solubility test on toxic substances (alkyl mercury, mercury, cadmium, lead, organic phosphorus, hexad chrome, arsenic, cyanide, PCB, copper, zinc,and fluorides):

1) Dredged material which releases either copper or zinc or a fluoride exceeding the standards levels.

2) Dredged material which releases any toxic substance other than copper, zinc, and fluorides exceeding the standards levels.

3) Dredged material other than those listed above.

When using the dredged material classfifed "1" in reclamation work, it must be made sure that the dredged material and seawater do not flow out into the sea and drainage standards provided separately must be met for overflowing water. Ocean disposal is permitted only for specified areas (Figure 2) after hardening those materials.

Dredged material classified "2" must be dumped in disposal sites isolated from the sea by watertight bulkheads. Though it may also be disposed of in the

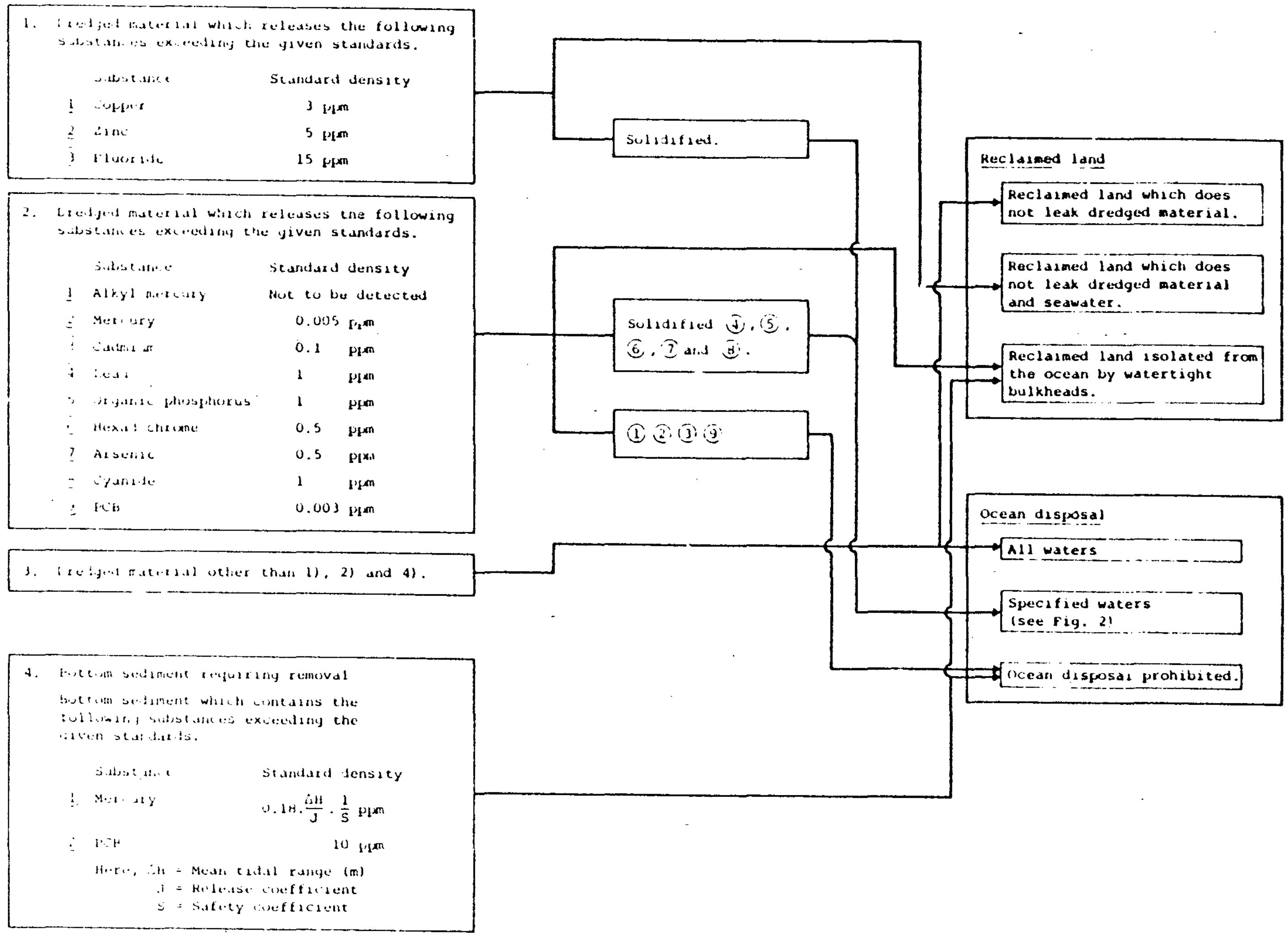
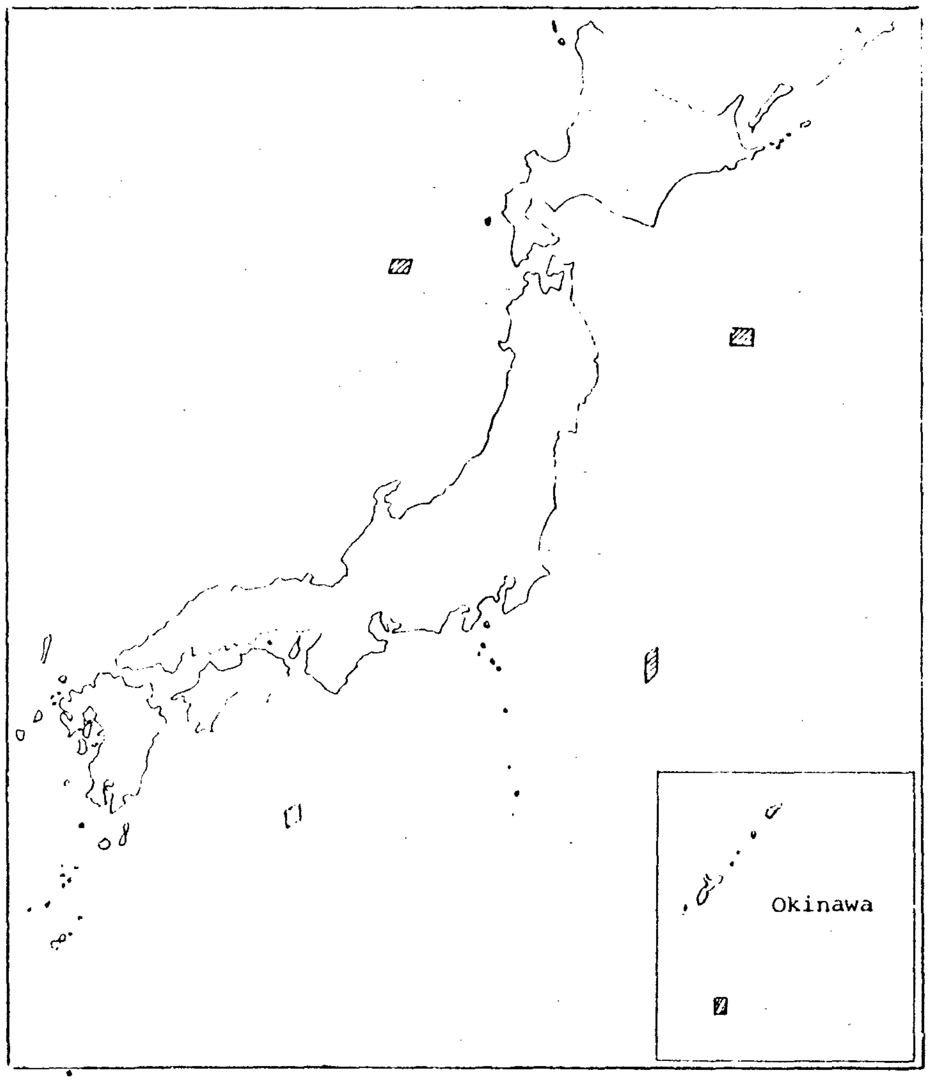


Figure 1. Restrictions on dredged material disposal



Specified waters

These areas of waters were determined after considering the following factors:

1 It should be outside an ocean current for the prevention of dispersion.

2 It should be outside a breeding area or a fishing ground.

Figure 2. Specified waters for ocean disposal of material containing toxic substances

above-mentioned specified areas after hardening, ocean disposal of those that contain alkyl mercury, mercury, cadmium, or PCB is prohibited.

The dredged material of category "3" may be used for reclamation work, provided it does not flow out into the sea; it may be disposed of at any sea area.

The above restrictions apply to the method of dredged material disposal. With bottom sediment that contains more mercury or PCB than the specified concentration, we take appropriate measures to improve the water environment, if necessary. This type of bottom sediment must be disposed of in the disposal areas of same type as those for dredged material classified "2".

In Japan, the Public Water-Area Reclamation Law prohibits reclamation not intended for specific land use. Sediment that contains toxic substances is used for reclamation after taking adequate environmental measures.

PRESENT CONDITION OF DREDGED MATERIAL DISPOSAL

In 1981, the dredged material produced by the government-related port works totalled 27 million m^3 in Japan. Almost all of it resulted from the dredging of navigation channels and mooring basins, of which 900,000 m^3 resulted from port pollution prevention works such as the removal of the bottom sediment polluted by industrial wastewater, etc. Of this, about 15% or 130,000 m^3 contained mercury or PCB exceeding the standard levels described earlier and thus required removal.

The remaining 85% of the dredged material from port pollution prevention works, and that from navigation channels and mooring basins hardly contained toxic substances. Therefore, the ocean disposal method could be adopted in accordance with the regulations. In reality, however, most of it was used for reclamation. The dredged material from rivers and fishing ports was also mostly used for reclamation. The reasons for this were: 1) agreement with fishermen was extremely difficult with regard to offshore disposal, 2) it was more economical to use it for reclamation than to transport it offshore. In addition, there is a strong demand for reclaimed land in densely populated metropolitan areas due to the shortage of land.

ECO-KINETIC MODEL FOR THE ACCUMULATION
OF PCB IN MARINE FISHES

Joseph M. O'Connor
John C. Pizza

INTRODUCTION

Contaminant loads to the marine ecosystem adjacent to New York and New Jersey have been well documented (Mueller et al., 1976; Mancini et al., 1982). Among the more important are the polychlorinated biphenyls (PCBs), due primarily to their abundance in the Hudson-Raritan system (O'Connor et al., 1982; Bopp et al., 1981), their toxicity (National Academy of Sciences, 1979), and their potential to cause chronic effects in animal and human populations (Kuratsune et al., 1976; Mehrle et al., 1982).

Most of the PCB contamination in the New York Bight derives from ocean dumping of sewage sludge and waste dredged material (Table 1). When relative PCB contribution from direct discharges is considered and integrated according to typical flow patterns in the Bight, expected water concentrations should be greatest in the vicinity of the N.Y. Bight ocean disposal sites (Figure 1). Actual data from a variety of studies show this to be the case (Figure 2). Based upon calculations from Tavolaro (1982) and O'Connor (unpublished), we have concluded that the elevated PCB levels to be expected near the Bight dumpsites derive in roughly equal portions from dredged material and sewage sludge. The increased PCB levels in the water column increase the potential for PCB uptake in all trophic levels of the Bight ecosystem (Wyman and O'Connors, 1980; Califano et al., 1982; Brown et al., 1982).

The majority of PCB placed in the Bight system with dredged material remains associated with deposited particulates. Coring studies at the dredged material dumpsite in the New York Bight (NYIMC, 1982) show that PCB levels vary with depth of core. The PCB levels at depth in many cores were equivalent to levels from various dredging projects. Ditoro et al. (in press) have shown that PCB mobilization from deposited sediments is slow, on the order of millimeters per year. Thus, the contribution of dredged material to PCB levels in the New York Bight water column is associated primarily with losses which occur during the dumping process. Tavoloro (1982) has estimated a dry mass loss of [illegible] during dumping; PCB losses during dumping may be on the order of 15% (O'Connor, unpublished).

With good reason, it has been concluded that activities that contribute to PCB levels in N.Y. Bight fishes should be minimized (MPRSA, 1972). In at attempt to determine how dredged material dumping affects

Table 1. Direct PCB Inputs to N.Y. Bight Apex, in Kilograms per Year

Source	Max.	% Total	Min.	% Total
Atmospheric[a]	490	7	34	1
Municipal Wastewater[b]	42	0.6	42	1
Dredged Material[c]	3500	51	1800	61
Sewage Sludge[d]	1300	19	750	26
Hudson Plume[e] (part.)	1037	15	62	2
Hudson Plume (dissolved)	480	7	240	8
Totals	6849	99.6	2928	99

[a] Assumes 1.14 m/year precipitation at 15 (min) and 215 (max) ng/ℓ PCB.

[b] 99.1 MGD direct wastewater flow; all secondary at 0.3 μg/ℓ PCB.

[c] From Bopp et al. (1981; min) and O'Connor et al. (1982; max).

[d] Based upon estimates from West and Hatcher (1980), Bopp et al. (1981), and O'Connor et al. (1982).

[e] Plume flow assumed to be 6.6×10^{10} ℓ/day, carrying 3 (min) and 50 (max) mg/ℓ solids at 0.86 μg/ℓ PCBs for particulate load, and 10 ng/ℓ (min) and 20 ng/ℓ (max) for dissolved load.

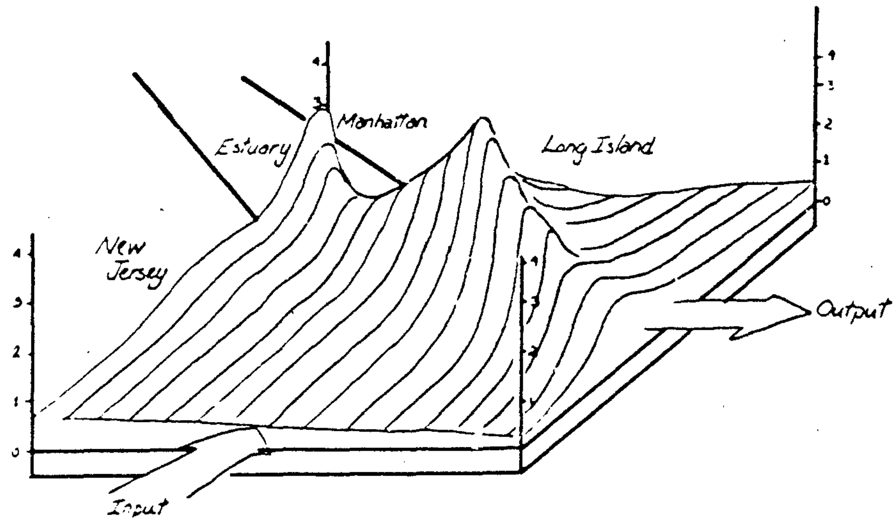


Figure 1. Generalization of a response surface generated by simultaneous mixing of PCB inputs to the Bight with relative concentrations of the contaminant shown by height above the planar surface

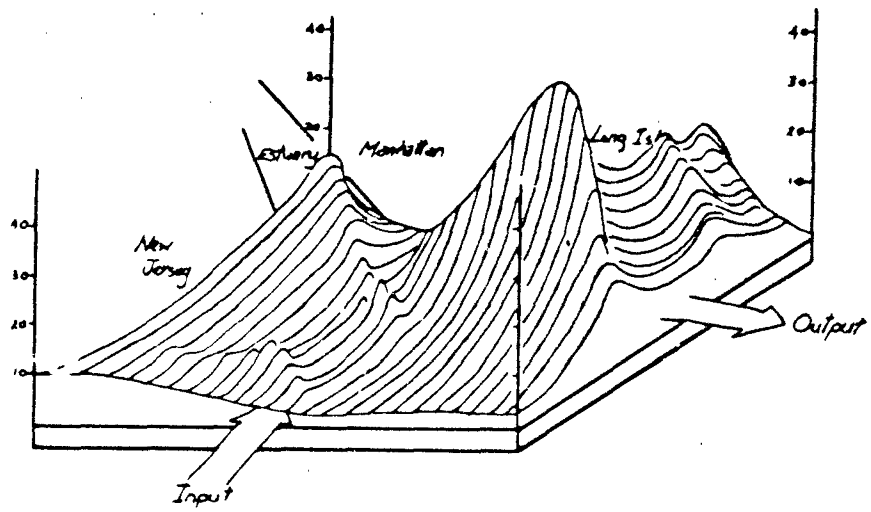


Figure 2. Actual data for PCB concentrations in surface waters of the New York Bight plotted as a response surface. The vertical scale is in ng/l. The data are from MacLeod et al. (1981), Pequegnat et al. (1980), Lee et al. (1978), and IEC (1981)

PCB body burdens in fishes, several investigations have evaluated the rates and routes of PCB transport in marine ecosystems. Once transport mechanisms are understood, predictive models may be formulated regarding the extent to which PCBs in sediment may cause increased body burdens. If a positive relationship leading to unacceptable burdens (e.g., 1 μg/g, 5 μg/g) can be related to mud dumping, managers and regulators can take steps to reduce or eliminate the problem.

Since the early 1970's it has been thought that fishes accumulated PCB directly from water (Hamelink et al., 1971; Needly et al., 1974). Experimentally derived bioconcentration factors (BCF) predictive of steady-state burdens in fishes have been published widely (Table 2); uptake mechanisms based upon octanol-water partition coefficients and lipid solubility of PCB have been proposed (Needly et al., 1974; Mackay, 1982).

Several factors mitigate against the equilibrium partition theory as the complete explanation for PCB burdens in marine fishes. First, the concept was developed using pure, dissolved compounds in relatively particle-free water. Under natural circumstances, seawater contains many particles to which PCBs are likely to sorb (Hiraizumi et al., 1979). For striped bass (*Morone saxatilis*), Califano et al. (1982) showed that the presence of particles in bioassay water decreased the quantity of PCB available for uptake, and that body burden was directly related to "available" PCB rather than total PCB.

Second, published BCF data generally derive from experiments of long duration, $\geq$ 5 days. Thus, organisms must be fed during the test, and the proportion of the PCB accumulated through contaminated food was not accounted for in these designs. Many studies have shown that food material, both living and dead, accumulates PCB rapidly (Wyman and O'Connors, 1980; Peters and O'Connor, 1982), providing a secondary route of PCB uptake in the test chamber. Peters and O'Connor (1982), for example, showed that *Gammarus* and *Neomysis*, common striped bass food organisms, accumulated up to 2 μg/g PCB from water in less than 10 hrs of exposure to a concentration of 1 μg/l. Inanimate food may accumulate PCB just as rapidly. Under such circumstances, BCF values calculated from long-term exposures almost certainly include a dietary component not accounted for in application of the data to equilibrium partitioning theory.

Third, and perhaps most importantly, equilibrium partition calculations for PCB bioconcentration generally yield estimates which are low, relative to field observations (Table 3). Given the potential importance of PCB in natural systems, we feel it is unwise to rely heavily upon such "order-of-magnitude" estimates. Given the knowledge that all parts of the marine food web contain PCB (MacLeod et al., 1981; O'Connor et al., 1982), and that cross-gut assimilation of PCB in fishes approximates 90% (Pizza, 1982), we stress that PCB in fishes derive in some

Table 2. Bioconcentration of Various Aroclors in Fish

Organism	Commercial Aroclor Mixture	Exposure Concentration ($\mu g\ \ell^{-1}$)	Exposure Time (days)	BCF[a]	Reference
Channel catfish (*Ictalurus punctatus*)	1248 1254	5.8 2.4	77 77	5.6×10^4 6.1×10^4	Mayer et al. (1977) "
Bluegill sunfish (*Lepomis macrochirus*)	1248 1254	2-10 2-10	chronic chronic	2.6 to 7.1 $\times 10^4$	Stallings and Mayer (1972)
Brook trout (fry) (*Salvelinus fontinalis*)	1254	6.2	118	4.6×10^4	Mauck et al. (1978)
Spot (*Leiostomus xanthurus*)	1254	1	56	3.7×10^4	Hansen et al. (1971)
Pinfish (*Lagodon rhomboides*)	1016	1	56	1.7×10^4	Hansen et al. (1971)
Rainbow trout (*Salmo gairdneri*)	2,2',4,4'-tetrachlorobiphenyl	1.6 and 9.0	5	2.9×10^4	Branson et al. (1975)
Fathead minnow (*Pimephales promelas*)	1248 1260	3.0 2.1	250 250	1.2×10^5 2.7×10^5	DeFoe et al. (1978) "

[a] Bioconcentration factor determined from the concentration in the fish divided by the concentration in the exposure water.

Table 3. Calculation of Expected PCB Body Burdens in Fishes from Equilibrium Partitioning Based upon New York Bight Data

	Min		Max
Water column PCB concentration (ng/ℓ)[a]	10		40
Particulate/dissolved ratio[b]	0.67		0.67
Dissolved (available) PCB (ng/ℓ)	6.7		27
Bioconcentration factor[c]	1×10^4		1×10^4
Expected concentration (μg/g fish)[d]	0.07		0.27
Observed concentrations (μg/g)[e]			
Striped bass		0.6–3.8	
Winter flounder		0.1	
Atlantic mackerel		0.5–0.7	
Bluefish		0.7–3.6	
American eel		0.5–0.8	
Tautog		0.6	

[a] Concentrations derived from Lee (1977), Lee and James (1978), IEC (1981), Pequegnat et al. (1980), and MacLeod et al. (1981).

[b] Various authors suggest particulate/dissolved PCB ratios ranging from zero to about 1. Based upon suggested values from Brown et al. (1982), Nau-Ritter (1980), and Pavlou and Dexter (1979), we arrived at a value wherein two thirds of the total water column PCB may be in the dissolved state.

[c] Based upon chronic bioassay data wherein values range from 1.7×10^4 to 6.1×10^4 (Table 2) for various species. Assuming some fraction to be associated with feeding, we suggest 1×10^4 to be a reasonable and conservative BCF approximation (see text).

[d] Calculated as (g/g PCB in water) x BCF, wherein the water value equals ng ($g \times 10^{-9}$) : 1030, the weight of 1 ℓ of seawater at 30 parts per thousand salinity.

[e] Data from O'Connor et al. (1982), N. Y. State DEC (1981), and sources cited therein.

significant part from the food; recently published models for contaminant transport in fishes and plankton demonstrate that dietary sources may be the prime determinant of PCB body burdens (Thomann, 1981; Brown et al., 1982) (Figure 3).

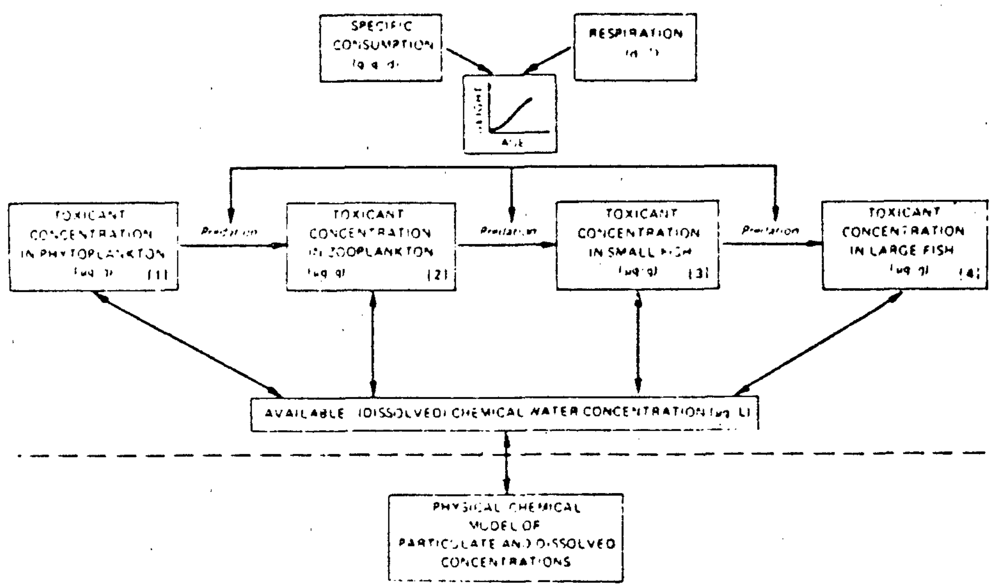


Figure 3. Schematic of the food chain model used by Thomann (1981) for evaluating the fate of microcontaminants in aquatic systems

Studies of PCB uptake from diet have been carried out in our laboratory for a variety of fishes and crustaceans (Califano et al., 1980, 1982; Califano, 1981; Pinkney, 1982; Pizza, 1982; Pizza and O'Connor, 1982; Califano and O'Connor, MS in review). The remainder of this paper provides the results of our food chain transport studies of PCB in striped bass. Utilizing these data, we propose a seasonally variable model to predict dietary accumulation of PCB in fishes. The concepts presented here are based upon pharmacokinetic relationships (Goldstein et al., 1974). Pharmacokinetics have been applied to questions of pesticide uptake in fishes by Krzeminski et al. (1977) and similar principles underlie the recent work of Thomann (1981) in his efforts to model PCB and cadmium accumulation in fishes.

METHODS

The techniques used in these studies were developed by Califano et al. (1982) and by Pizza (1982). Complete details of the pharmacokinetic approach to PCB studies are available in Pizza (1982); see also Pizza

and O'Connor (1982). To summarize, an evaluation of the assimilation and excretion of a compound requires empirical data as to the rate of assimilation from the absorption site (K_a), and the rate of loss of the compound (K_e) from some physiological pool; the pool we used was the entire body mass of the subject organism. The mathematics are straightforward, and based in both cases (K_a; K_e) upon the exponential expression for a decay curve:

$$M = M_o e^{-K_a t} \text{ (for absorption)} \tag{1}$$

where M_o is the quantity of PCB placed at the absorption site, M is the quantity remaining at time t, and K_a is the absorption rate constant.

Elimination rate constants (K_e) are derived from the same expression with different notations:

$$X = X_o e^{-K_e t} \tag{2}$$

where X_o is the whole body PCB level at time zero, X is the whole body PCB burden at time t, and K_e is the elimination rate constant.

Values for PCB assimilation were determined by force-feeding striped bass known quantities of ^{14}C-labeled PCB (Aroclor 1254) in natural food, and sampling at fixed intervals to determine: 1) the quantity of PCB in the gut; 2) the quantities of PCB in the whole body; and 3) the quantities of PCB in fecal material. Sampling of fishes continued for a period of 120 hrs. Tissues were analyzed for total ^{14}C-PCB by liquid scintillation counting (Pizza, 1982).

Separate experiments were conducted to determine K_a and K_e from single and multiple feedings. Manipulation of the empirical data conformed to treatments suggested by Goldstein et al. (1974). The equations are documented in Table 4.

RESULTS

When striped bass were given single doses of PCB there occurred initial and rapid elimination from the alimentary tract followed by a phase of less rapid elimination (Figure 4). The whole body burden (Figure 5) remained monophasic. Note that, after 48 hr, when alimentary tract burdens were <10% of the dose, the whole body burden was high, reflecting nearly complete assimilation of PCB from the natural food matrix. For a single PCB dose, the body burden will follow a time course reflective of the ratio K_e/K_a, as shown in Figure 6.

Table 4. Pharmacokinetic Expressions Applied to PCB Dietary Uptake Studies

A. Absorption rate (K_a)	$M = M_o e^{-K_a t}$
B. Elimination rate (K_e)	$X = X_o e^{-K_e t}$
C. Absorption half-time $t_{1/2}$	$t_{1/2} - \frac{-\ln 0.5}{K_a}$
D. Fractional absorption-single dose	$X/M_o = 1/[(K_e/K_a)-1](e^{-K_e t K_a} - e^{-K_e t})$
E. Time to maximum absorption - single dose ($K_a \neq K_e$)	$t_{max} = 2.3/(K_a - K_e) \log K_a/K_e$
F. Maximum fraction absorbed - single dose	$X_{max}/M_o = (K_a/K_e)^{K_a/K_e - K_a}$
G. Body burden at end of dosing interval - multiple doses	$X = X_o e^{-K_e t^*} + X_o (e^{-K_e t^*})^2 + \ldots + X_o (e^{-K_e t^*})^n$
H. Body burden after dosing - multiple doses	$X_n = X_o (1-e^{-K_e t^* n})/(1-e^{-K_e t^*})$
I. Plateau (steady-state) burden - multiple dose	$X_\infty = X_o/1-e^{K_e t^*}$
J. Fraction of plateau at "n" doses	$f = 1-e^{-K_e t^* n}$

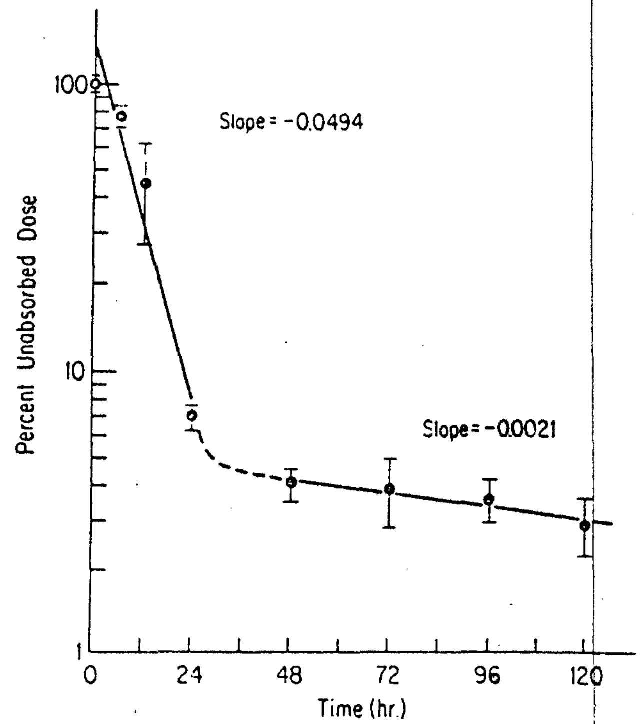


Figure 4. Percent unabsorbed dose as a function of time. PCB removal from the alimentary tract as determined by two processes: 1) absorption of administered dose (slope = -0.0494); and 2) elimination from tract tissue (slope = -0.0021)

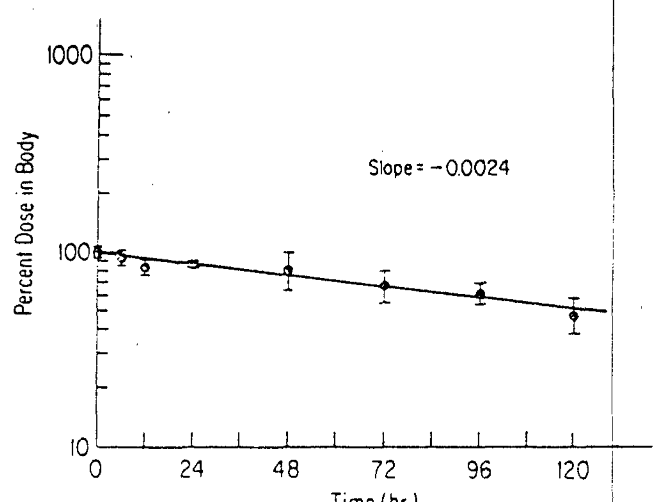


Figure 5. Percent dose in body as a function of time. PCB elimination from whole body implying single compartment kinetics

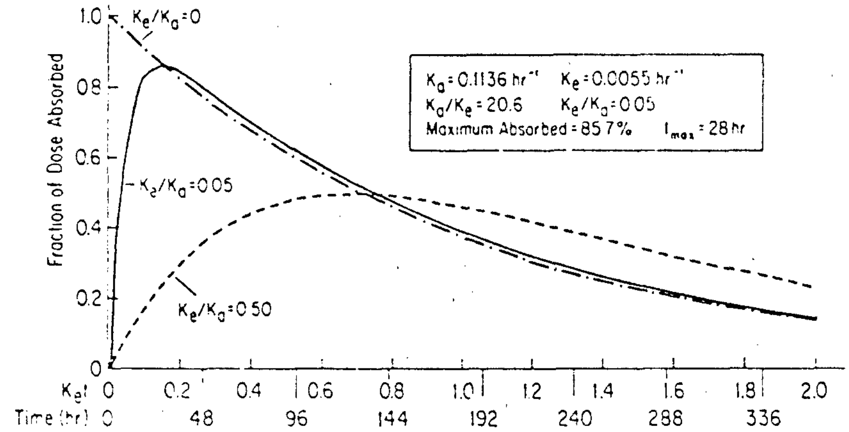


Figure 6. The fractional absorption of a single dose by first-order absorption and elimination. The solid curve was determined as in Table 4 and the data of the current study where $K_e/K_a = 0.05$. A maximum of 85.7 percent was absorbed by 28 hr. The other curves are presented for comparison (Goldstein et al., 1974) at the same K_e. The case where $K_e/K_a = 0$ ($K_a = \infty$) is attained by constant input rate. For $K_e/K_a = 0.50$, where for a K_a smaller than that of the solid curve, a lower maximum would be attained at a later time

Fishes in contaminated environments, however, do not accumulate PCB as single, isolated dietary doses. Rather, they contain PCBs derived from water uptake and they receive multiple, sequential doses of PCB in food. Our multiple dose study showed the gradual approach to plateau (Figure 7) expected for young striped bass exposed to sequential doses of PCB in food at 48-hr intervals. The interval was chosen in order to observe the approach to steady-state. This is unrealistic, in that the feeding interval in nature is more likely to be twice each day. Mathematically, this is unimportant; what is essential is that the kinetics of the system (see Table 4) show plateau reached at dose n = 17. For a fish feeding twice each day, plateau would be reached in 8.5 days.

APPLICATION TO MODELING

Thomann (1981; see Figure 3) documented clearly the level of complexity required in meaningful models of contaminant accumulation in fishes. In his model he noted: 1) the lack of data relevant to the function referred to as the "food-chain multiplier"; and 2) the need to account for age-specific changes in respiration, feeding, and growth as determinants of predicted PCB body burdens in striped bass. In the preliminary model presented here, we provide the food-chain multiplier, as influenced by growth of the fish, changes in metabolism, changes in food ration, and changes in dietary PCB levels.

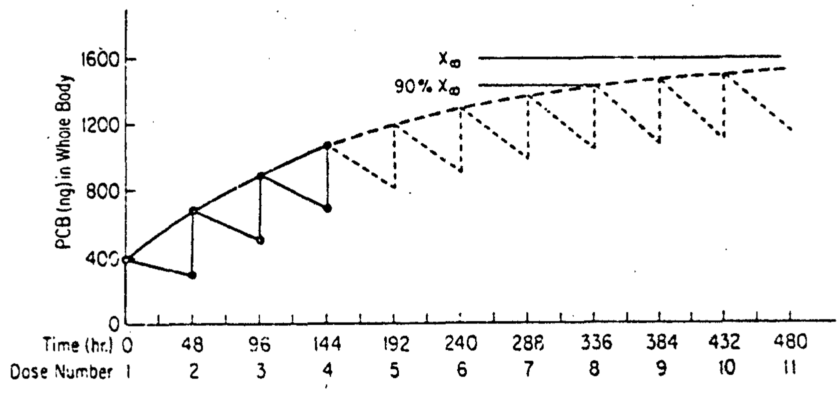


Figure 7. Curve for the cumulative retention of PCB from multiple dosing. Solid lines present actual levels attained during experiment. Dashed lines are the calculated extension of the data. The plateau burden (X_∞) is the steady-state level attained from peak values after sufficient dosing (see text)

Pizza's analysis (1982) of striped bass PCB accumulation from diet revealed that changes in plateau PCB burden depended upon two factors. The first is the K_e. The second is the dosing interval at which new PCB is taken in via the food. The relationship between physiological growth in the striped bass and required ration size, as well as weignt-specific metabolism, is depicted in Figure 8, along with the expected effects that changes in these factors may have on food assimilation efficiency and the elimination constant (K_e) for PCBs (Califano et al., 1982; Pizza and O'Connor, 1982). The physiological data suggest that, for a growing fish, there should be no steady-state PCB level; since metabolism (and, hence, K_e) declines with age, and since assimilation efficiency declines with increasing age and ration required for growth increases, the PCB body burden should increase continuously. Further, since the volume of water required for oxygen exchange must increase with size, more direct water uptake of PCB is possible. The importance of the latter in contributing to body burden may be questioned, however, since respiratory requirements may be extremely variable depending upon ambient levels of dissolved oxygen, temperature, time of day, time in the feeding cycle, etc. (Neumann et al., 1982).

The pharmacokinetic model incorporated these relationships under conditions representative of striped bass biology in the Hudson estuary. These were:

1. Active feeding during the first growing season on zooplankton containing 5 µg/g (dry weight) PCB (O'Connor et al., 1982).

2. A growth rate of 0.02 d^{-1}.

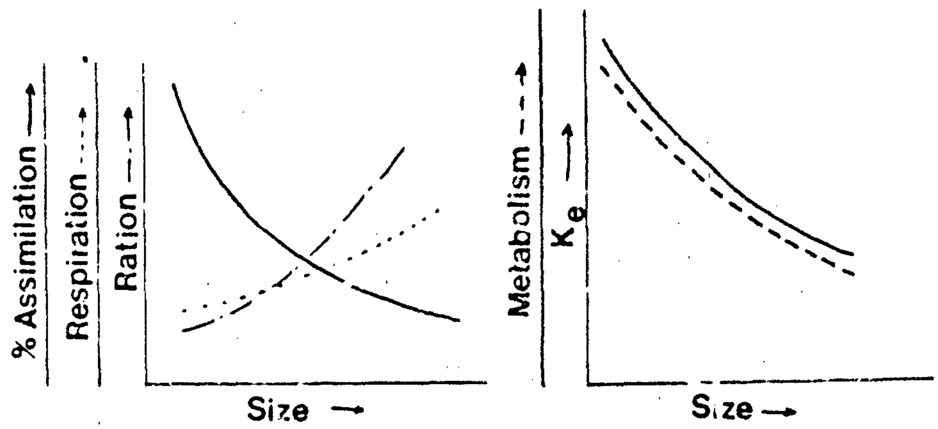


Figure 8. Schematic representation of the response of various physiological parameters to increased size of the organism. In the left figure, required ration to grow and respiration (μg O_2 per hour per individual) increase with increased size; assimilation efficiency of food decreases. In the right figure, metabolism- and elimination-constant K_e decrease with increasing size

3. Decreasing K_e at a rate proportional to weight; $W^{0.7}/W$ (Brett, 1979).

4. Increased ration size to maintain a daily intake of 10% body weight.

5. A feeding interval of 12 hr, with one-half the daily ration (and PCB dose) consumed during each feeding period.

6. Additional feeding during the second growing season on zooplankton containing 0.5 $\mu g/g$ (dry weight).

7. An optional "overwintering" period during which K_e decreased as a function of temperature (Neumann et al., 1981), and feeding was reduced to 48-hr intervals (once each two days; Lawler, Matusky and Skelly Engineers, 1980).

The model was run in two modes. In Figure 9 we present the outcome of the model incorporating factors 1 through 7 above. In mode 1 (solid line) an artificial 330-day feeding/growth period was imposed, during which the bass were continuously exposed to food containing 5.0 $\mu g/g$ PCB. Mode 2 (dashed line) reflects the "natural situation," fish fed for one growing period on food containing 5.0 $\mu g/g$ PCB; during the

second growing period (days 150 through 330) the food contained 0.5 μg/g PCB. These values reflect the natural habitat during year II.

The pharmacokinetic model showed that the dietary uptake of PCB could account for about 3.8 μg/g (dry weight) in the course of the first 150-day growing period. This translates to ∿1 μg/g PCB (wet weight) expected in fishes occupying the brackish water portion of the estuary. Expected concentrations due to equilibrium partitioning for this portion of the river (see Table 3) would be ∿0.3 μg/g. Califano et al. (1982) showed young-of-year bass from the same river region to contain 1.6 μg/g total PCB (wet weight). The dietary component, therefore, could represent about 63% of the observed PCB burden in young striped bass from portions of the Hudson where dietary PCB burdens are high.

Given a change in dietary PCB burden from 5.0 to 0.5 μg/g PCB, which could be accounted for by migration or change in food preference during a second growing season, we predict a decreased body burden (Figure 9). Following a loss from 3.8 to about 0.5 μg/g (BAF = 1) growth, increased ration and declining K_e cause re-initiation of PCB build-up to ∿0.8 μg/g (dry weight) after a total of 330 days (or 180 days on the reduced PCB diet). This value (∿0.2 μg/g wet weight) represents from 32 to 87% of the whole body PCB determined in year II striped bass from river regions where food organisms contain ∿0.5 μg/g (Lawler, Matusky, and Skelly Engineers, 1980; 0.23 to 0.63 μg/g PCB in striped bass, n = 4). With an expected equilibrium partitioning value of 0.07 to 0.2 μg/g (Table 3), we conclude that PCB uptake from a diet containing low levels of PCB remains important to the organismn. In no case can equilibrium partitioning be shown to account for the total PCB in striped bass.

The effect of reducing dietary PCB intake is dramatic in the model output. Note in Figure 9 that within 30 days the expected body burden dropped to about 0.5 μg/g and, with continued feeding at low PCB levels, the expected PCB burden at day 302 is about 0.8 μg/g. Beyond the final values of the prediction, Figure 9 demonstrates several important points relative to ecology, growth, and PCB accumulation from dietary sources.

First is the concept of steady-state. Our results show that, regardless of PCB source, a steady-state body burden is unlikely to occur in any environment other than a controlled chronic bioassay study with no growth. In the real world, any change in PCB intake due to change in water concentration or PCB dose in the diet will, due to the continual change in K_e, result in a shift toward a new plateau level.

Second is the concept of growth-related bioaccumulation factors. In Figure 9, the findings of mode 1 and mode 2 model runs result in rather different rates of PCB bioaccumulation; however, when viewed from the perspective of dietary burden, one can see that for any given point in time, the ratio K_a/K_e is the same for mode 1 and mode 2. The differences in actual rate of accumulation (g/day PCB) exist because, while rate of elimination (K_e) is a first-order function, the growth-related decline in K_e will result in acceleration of the accumulation

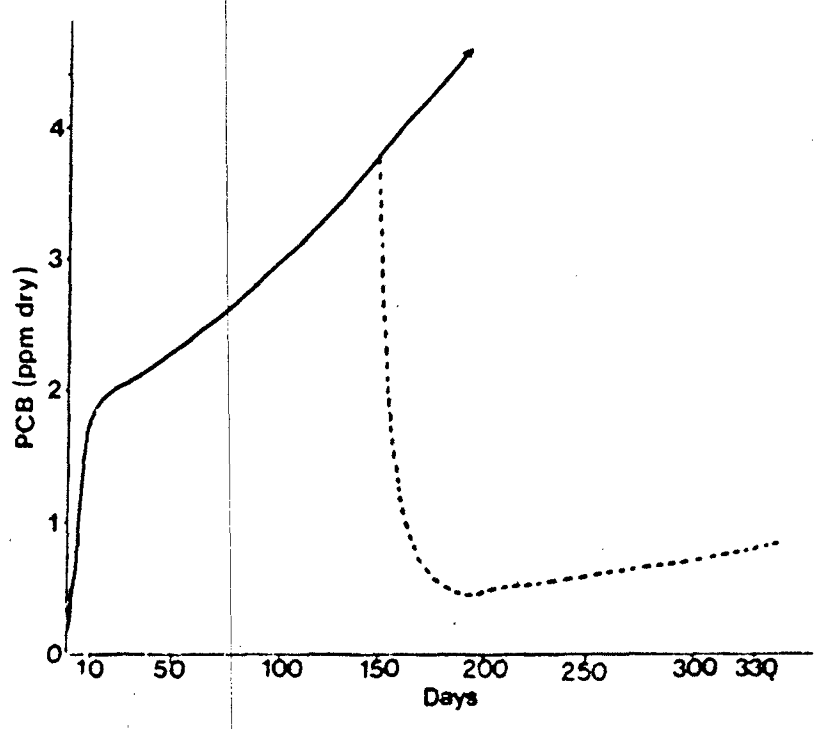


Figure 9. Predicted PCB accumulation, as ug/g (dry weight) PCB in the whole body of striped bass exposed for 330 days to a diet containing 5.0 ug/g PCB (Mode 1; solid line), and for 150 days to 5.0 ug/g PCB followed by 180 days exposure to a diet containing 0.5 ug/g PCB (Mode 2; dotted line)

rate as soon as a plateau is reached. At the higher feeding rate, the curve has a sharp upward trend. At the lower rate of PCB dosing, the acceleration of the rate is less obvious since body burdens were reduced markedly by the reduced rate of dosing, and have remained low during the extended period of low-level feeding.

Third, and perhaps most important, is elucidation of the concept of an immediate shift toward a new plateau level when PCB source terms change. Thus, for striped bass in a natural system, where water concentrations of PCB are relatively uniform, one might expect the following to be true:

1. Striped bass from ocean environments, where PCB levels in food are low, should contain lower body burdens than fish from inside the estuary.

2. PCB burdens in striped bass should be lower during winter (nonfeeding) months compared to the same site during growth periods.

3. Any migratory behavior which results in a change in dietary PCB burden will rapidly be reflected in a shift toward a new body burden plateau.

4. Low levels of PCB in the diet (e.g., 0.5 μg/g) will not, in the course of one growing season, cause body burdens to exceed present or proposed FDA guidelines for burdens in fishes.

5. Widespread increases in water-column PCB levels could become important in marine toxicological questions if this were to increase burdens throughout the food chain and raise water-derived levels by a measurable degree.

6. The tendency to undergo rapid shifts toward new PCB plateaus renders localized PCB "hotspots" of minor import in otherwise "clean" marine systems when the organism in question is mobile, pelagic, and highly migratory.

The likelihood of verifying these expectations with existing field data is low; much depends on accurate determination of water and food chain PCB values, careful sampling of year classes for PCB analysis, and sampling efforts aimed at the proper location-season-specimen regime. We have, at this time, undertaken to formulate these expectations as hypotheses, and are testing them in the New York metropolitan region.

As a final note, we hasten to point out that our empirical and modeling data have direct application to ongoing ocean dumping studies as follows:

First, our hypothesis that PCB burden in fishes is strongly related to diet renders the "mass loading" approach to ocean PCB pollution ineffective in estimating contaminant levels in fish. Both dredged material and sewage sludge must be evaluated more carefully to assess real quantities of PCBs injected into the food chain and the water column.

Second, the pharmacokinetics of PCBs in fishes suggest that any isolation of contaminated materials from entry to the food chain will have the effect of lowering PCB body burdens in the large, predatory species which often form an important part of the human diet. Thus, maintaining a surficial layer of sediments with low or nonavailable PCBs will, in all likelihood, result in a trend toward lower body burdens in all trophic levels.

Third, the overall outcome of the model suggests that we shall not see increased PCB levels in fishes if input rates and input sources remain similar to those of recent years. While we do not advocate use of the ocean as unrestricted dumps, we do suggest that, with time, the input of bioavailable PCB to New York marine waters has achieved a balance; it appears that any impacts which have occurred are not irreversible, although their description is unclear. Further dumping regulations should include attention to rendering such contaminants as PCB, first, unavailable to food chains, and, finally, unavailable in the water column.

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ASPECTS OF THE DAMOS
MONITORING PROGRAM IN
THE NEW ENGLAND REGION

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ABSTRACT

A synopsis is given of an ocean monitoring program designed to assess the impact of disposal of dredged material. The program extends to sites which have differing physical characteristics, thus requiring some individualistic treatment. Important criteria in terms of equipment capabilities are cited, and measures utilized to monitor physical, biological, and chemical parameters are described. The use of sentinel organisms, especially *Mytilus edulis*, is an important component in the program design. The program, in its present state, has been employed for five years in the New England region.

While the necessity for assessing the state of our ocean waters is readily endorsed by both the scientific community and body politic, the means by which this may be achieved continues to be a most difficult challenge. This paper, by tracing the experiences gained over a fifteen-year period by our organization in managing contaminated dredged sediment, may provide some insight to the many problems which are encountered in monitoring programs.

Monitoring programs are usually conceived for the purpose of (1) providing warning against imminent harmful impacts from recognized sources, and (2) evaluating and forecasting long-term impacts. While a single monitoring program may well satisfy both of these objectives, the strategies adopted for each may vary considerably, and may greatly affect the resource requirements. However, because monitoring strategies for ocean programs also need to be individualized, both in a geographic sense and to discriminate between specific influences, there is no simple method to arrive at an acceptable design. There are many lessons to be learned during the initial period, for which there appears to be no substitute.

Our progress in monitoring programs thus far has been guided by necessity for purposes of compliance, and as a tool for management of dredged material. Notable successes have been in the areas of developing reliable methods, hardware, and technology in the initial phases, which allows greater freedom and flexibility in addressing demands placed on the program. These successes include methods for precise measuring of bathymetric change, marking devices for guidance and control, tracking and locator devices for control and instrumentation, and a well-integrated system of support services. With these in place, we were able to develop advances in disposal techniques involving capping (Morton, 1980), as well as to expand the program to encompass the entire geographic area of our responsibility.

While much of our initial activity has centered around the region of Long Island Sound, which to some extent represents estuarine conditions, the techniques we found in most cases were readily adaptable to deeper ocean sites. Too much cannot be said for having a hospitable environment in which to develop one's hardware. Moreover, the depths of water in the sound, 20 to 30 meters, has allowed for more critical observations by divers of both physical and biological phenomena than could otherwise be obtained.

The present monitoring program, now known as DAMOS, in the New England region has evolved over a period of 15 years of observing dredged material disposal. The program focuses upon 12 disposal areas whose distribution coincides with the location of major dredging activity. This activity, in turn, is regulated by the shipping needs of major ports whose commerce is predominantly petroleum imports. The sediments associated with this dredging are frequently contaminated by petroleum residues, various metallic compounds generated by the industrialized cities, and a variety of other compounds which include pesticides and chlorinated hydrocarbons. Because the region is rich in fisheries resources, it is essential not only to avoid conflicts in disposal area siting, but to provide reassurance to the public that food sources are not being contaminated.

Each disposal site has been designated after extensive consultation with fisheries interests, and only after a screening of physical characteristics and an inventory of biological activity of the location. One attribute of historically used disposal areas is that many have become prolific lobster grounds, and in three instances, it has not been possible to regain their use because of fisherman pressure. Limited studies of lobster populations of historic dumping grounds has revealed no adverse characteristics attributable to this habitat. Being compelled to abandon dedicated disposal sites, of course, adds additional pressures to the regulator's task, since lobstering and dumping grounds are also incompatible with other forms of bottom fishing. As a general and very unprofound statement, I will offer that science cannot begin until the smoke of political battles has settled.

The protocols now being followed in each area are generally similar with respect to method, but are also tailored specifically to the depth of water and exposure conditions, as well as to the extent of usage by the dredgers. These may be categorized into a typical, physical, biological, and chemical array.

Physical monitoring is that which looks for gross or catastrophic effects due to movement of materials during and after disposal operations, particularly following major storm events. The hardware currently in use was developed over a period of years to perform the desired function, which is, basically, to establish a grid over a given area and to replicate accurately measurements for comparison over time. Our system utilizes an Apple II microcomputer interfaced with a Model 540 Del Norte Trisponder and an EDO Western multi frequency fathometer system. Data are recorded on "floppy disk" media for rapid acquisition and comparison of data and to allow visual displays for control of the vessel. Other types of positioning systems such as LORAN-C can be interfaced to the equipment for more flexibility in the survey, sampling, or disposal management activities. Bathymetric surveys are run on 25-meter lane intervals, giving more than ample resolution and discrimination of volumetric changes in disposal mounds.

Utilizing this equipment and methodology our program now has records of disposal activity in each of the major dumping grounds, beginning with the pre-disposal condition, during dumping, and at intervals following. This allows an assessment of any gross physical change together with correlation to any other observed phenomena on the site. The technique has worked equally well in Long Island Sound at a depth of 20 meters, and in the Gulf of Maine at depths of 60 meters. The ability to maintain consistent records is essential to any evaluation of long-term effects. Morton (1980) has reported extensively on the effect of hurricane force wind-induced-stresses on a disposal mound.

While current measurement, particularly in the near bottom layers is important to evaluating site conditions, especially in predicting stability of any deposit, the means of instrumentation over extended periods requires refinement. Our program has had success in maintaining various arrays of current and suspended solids sensing equipment which has yielded useful data (DAMOS ANNUAL REPORT, VOL. I, 1980). However, the reliability of such equipment beyond 10 days is often compromised by marine organism fouling. This argues for more intensive developmental effort since major meteorological events which are the sought after records do not always cooperate with cruise schedules.

With the amount of information we have acquired to date regarding physical regimes which apply to each disposal site, we are within reach of producing a mathematical model which will be useful to the regulator. As such models are refined, prediction of resulting bottom conditions and management response will be considerably improved. If the premise is true that the physics of an area governs the biology, then we are not far from what is theoretically possible in competent prediction of site conditions resulting from disposal.

The biological component of our monitoring experience has been most intriguing because of the inherent variability of conditions at our ocean sites. It seems that everyone has a favorite indicator species which relates pollution effects on living resources to predictability of impact upon humans. We have, of course, made hundreds of observations of population dynamics, body burden, and other parameters both in the field and in the laboratory, but choosing the one, or the set, is a most difficult task.

There is much to be said for studying fish species which are directly consumed by man as a monitor of potential adverse impacts. We intend to expand upon this phase of our activity in future programs as we gain familiarity with appropriate species and background conditions.

For four years now we have been utilizing sentinel organisms at each major disposal site. The bivalve mollusc, Mytilus edulis, was chosen for its ubiquity and sessile existence, as well as its recognized commercial and ecological importance. It has been used by many investigators for some years, is well documented in the literature, and is the principal organism used in the Global Mussel Watch Program. This phase of our program is conducted under the direction of Dr. S.Y. Feng of the University of Connecticut. His reports on the temporal and spacial variations of trace metal levels, PCB levels, and physiological conditions of these sentinel mussels are contained in DAMOS Reports 20 thru 22, and the 1980 Annual Report, among others.

The findings to date encourage us to continue to utilize both the blue mussel and the horse mussel (Modiolus modiolus) both from the standpoint of measurable response to changing bottom and water quality conditions, and from the standpoint of convenience. Given the sometimes arduous conditions under which ocean monitoring is conducted and the high cost of sustaining vessel and laboratory operations, any methodology which simplifies the job must be counted as a blessing.

Feng (1982) in his report on deployment of the sentinel mussels at the capping experiment site in Central Long Island Sound gives further insight into monitoring design and strategy. The results of analysis for heavy metals indicate that peak concentrations tend to occur during periods of increased suspended load in the water column attributable both to natural meteorological events and dredged material disposal. These observations compare with sediment transport studies being conducted under the program, which show also that the temporal and spacial effects of dredged material disposal are several orders of magnitude smaller than those induced by natual storm events.

These observations further correlate with similar studies conducted in Eastern Long Island Sound which suggest that the observed temporal variation of trace metal concentration in mussels is strongly influenced by a variety of factors such as river runoff.

Since inception of our disposal area studies we have relied a great deal upon sampling from surface vessels by conventional apparatus with accompanying analyses of diversity and density of colonizing species. Over this same period, however, we have compiled an extensive library of underwater photos and diver accounts of observed phenomena which contribute measurably to understanding sediment behavior and dynamics, as well as biological activity. Wherever site conditions allow, both diver observation and photography improve the confidence level of the program manager in his interpretation of data greatly, and justify the extra effort and expense where necessary.

Chemical analyses are carried on concurrently with all biological sampling and in conjunction with cores taken on site, both by surface craft and by diver. As the chemistry data begin to accumulate, we see some interesting relationships which may be of possible significance to later management activities. In general, the cores taken have been used to confirm visual observations of dredged material transport or mound behavior, and it is clearly possible to associate material on the dumpsite with its origin, based on pre-dredging analyses.

Thus we see the possibilities of correlations being drawn from biological, physical, and chemical parameters which would allow the manager to better discriminate between short-term and long-term as well as man-induced versus natural occurrences. This argues strongly for the design of any program to consider the means by which perceived impacts can be analyzed from more than one perspective.

An extremely important offshoot of our experience with the monitoring program was the application recently of many of these techniques to the selection of a new disposal area in western Long Island Sound. Once the primary characterization of the region, consisting of commercial fisheries surveys, overall topography, and wave climate, had been developed, the process of refinement and definition of optimum conditions was initiated. Overall bathymetry was evaluated using side scan sonar combined with the fathometer system to generate a contour chart. The side scan proved to be a valuable interpretive tool for purposes of identifying bottom sediment characteristics. The area tentatively selected from these records was extensively sampled to confirm sediment character, and samples were analyzed for baseline information. Current meters deployed during the survey, together with wind and suspended sediment data, provided useful comparative information. Benthic sampling combined with diver transects tended to confirm the bottom conditions revealed by physical measurements. Ultimately, a bottom feature resembling a trough was considered to afford the optimum depositional site condition to meet the requirements of regulation and to avoid conflict with other users. Surveys subsequent to initiation of use of this site confirmed that the specifications were being met in all respects (DAMOS, CONTRIBUTION #19 1982).

The interesting relationships to which I refer have intrigued scientists for some time, but have not been pursued a great deal in research. This has to do with the fact that, because of their potential harmful effects, attention until now has been directed to detection and measurement of heavy metals and various toxins. There has been a corresponding neglect of possible beneficial effects that may result from the disposal of dredged material at sea.

In our initial attempt to characterize two regimes, the North Atlantic Tidal System and the Gulf of Maine Tidal System, we have compiled bulk sediment analysis data from cores and grab samples from approximately one hundred New England harbor bottoms. A natural extension of this analysis would seem to lie in evaluating the effectiveness of these organic sediments as fertilizers when they are dumped at sea in fishing ground areas, that is,

to examine the sediments by breaking down their organic fractions into estimates of their various components to see what they might have to offer by way of enrichment and enhancement of primary productivity. Theoretically, it appears that this could become a strategic component of disposal site management, with the same degree of predictability that is being developed for physical attributes.

The intriguing possibility of maximizing the productivity potential of the ocean bottom of course goes beyond the original objectives cited for monitoring programs, which were compliance and long-term or trend assessment. However, it is an indication that monitoring programs are capable of developing good scientific information in the course of serving other purposes. It seems to make good sense, considering the high expense involved in mounting marine studies, to attain optimum benefit from the effort.

While I have touched upon some of the facets of our program which I believe are distinctive, I must also emphasize that proper organization and operation of a successful monitoring program involve much more. Quality control, integration with other programs, possibly of wider scope, and provision for information transfer are equally vital aspects.

The subject of quality control is far too extensive for the purpose of this paper. It is as much a function of design of the program as are the other components. Our own experience thus far has been satisfactory on a regional basis because of the relatively few participants in the program. Obviously, the correlation of information of one program with another will require far greater effort on all participants with regard to inter-laboratory calibration and other considerations.

As a concluding note, I suggest that those who engage in design of monitoring programs guard against the tendency of scientists to "compartmentalize" along special disciplines. There is little question that it is easier to work this way, but it does not serve the project nearly so well as does an organization along inter-disciplinary lines. Our program has certainly benefited from this principle, as have the individuals who must utilize its findings.

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AN OVERVIEW OF A DREDGING DEMONSTRATION IN CONTAMINATED MATERIAL, JAMES RIVER, VIRGINIA

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ABSTRACT

The James River, Virginia, is a tributary of the Chesapeake Bay polluted with the toxic pesticide Kepone. The Norfolk District of the Corps of Engineers accomplished maintenance dredging operations within the polluted portion of the James River channel during fiscal year 1982. As part of the channel maintenance, the District conducted a demonstration of a dredging method designed to contain and remove a polluted layer of sediment with a minimum of resuspension. The method involved modifying and fitting an existing dustpan suction head to a contractor's cutterhead dredge. The dredge was then operated using an anchoring and maneuvering wire arrangement that enabled precise positioning of the suction head within the specified layer of polluted sediment. Monitoring of operating parameters onboard the dredge, of resuspension at the suction head, and of water quality around the dredge and disposal area was accomplished with appropriate equipment. The dredge was also operated in the conventional cutterhead configuration for comparison with the dustpan arrangement. The data gathered during this demonstration project permitted evaluation of the dredging and disposal methods utilized, and will be useful in planning future projects in the James River and other sites involving polluted dredged material.

INTRODUCTION

The Norfolk District is located in Virginia, and includes the lower half of the Chesapeake Bay with its many tributaries, as well as a portion of the Atlantic Coast. In serving the nation, the maintenance of navigation channels and harbors is one of the most important missions. We have over 60 authorized navigation projects that are active, totaling over 700 miles (1100 km) of waterway. Depths in these channels vary from 4 feet (1.2 m) in the smallest, to 45 feet (13.7 m) in the largest harbor projects.

Our deepest projects serve the vital ports of the Hampton Roads area, where eventual deepening to 55 feet (16.8 m) is planned. Hampton Roads also provides deep-water access to the James River, one of our more important tributaries.

BACKGROUND

The James River (Figure 1) generally flows easterly, from the Allegheny Mountains of western Virginia, to its mouth at Hampton Roads and into the Chesapeake Bay. Between the City of Richmond and the mouth, a distance of 90 miles (145 km), the James is tidal and navigable. In this portion of the river, a navigation channel 25 feet (7.6 m) deep is maintained to serve the ports of Richmond and Hopewell, and the industries between these cities. These industries and port activities depend on the James River Channel for the economical transport of many commodities and raw materials. As is the case on many of the world's waterways, local industries have created pollution. In particular, the Allied Chemical Corporation, at plants in the vicinity of Hopewell, Virginia, was responsible for the release of Kepone into the James River system. Between 1967 and 1975 it is estimated that as much as 65,000 pounds (30,000 kg) of the highly toxic chemical was discharged into the James River basin.

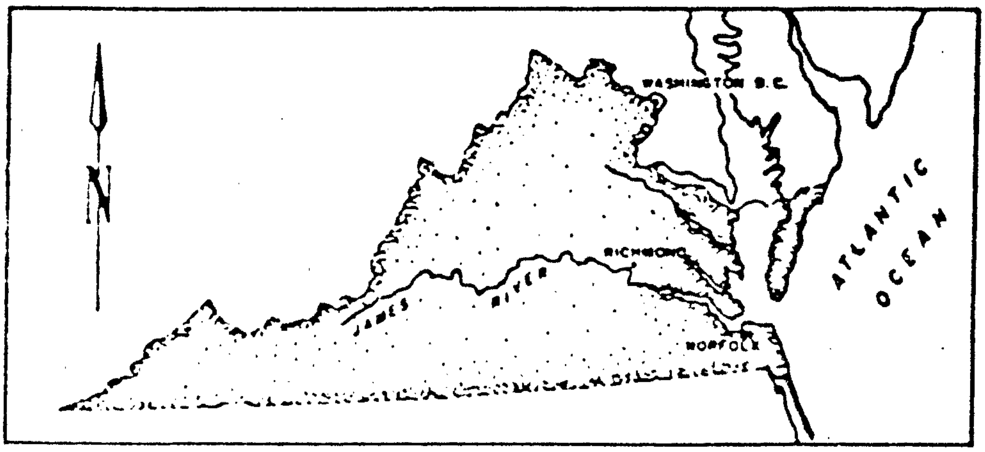

Figure 1. Location of James River, Virginia

Following discovery of the extent of Kepone pollution, and formation of State and Federal task forces, the U. S. Environmental Protection Agency (EPA) conducted the Kepone Mitigation Feasibility Study. As part of this effort, the Norfolk District was requested to evaluate alternatives for the removal of Kepone-contaminated sediments, and to investigate potential dredging technology and methods to control resuspension and secondary pollution. During this mitigation study, a delegation from EPA and the Norfolk District visited Japan to observe specialized methods of handling toxic sediments. The group was favorably impressed with the Oozer Dredge because of its alleged ability to achieve a high solids-to-water ratio and minimize resuspension. As a result of the Japan visit, the Norfolk District recommended that a demonstration project be conducted on the James River to evaluate the Oozer Dredge in comparison with a conventional cutter suction dredge. The basis for the recommendation was that there would be a need to know the best method of removing pollutant "hot spots," whether consisting of Kepone in the James River or toxics in other areas of the country, if the Corps were assigned a cleanup mission.

The recommendation to conduct a demonstration project was made to higher authority in early 1979, and resulted in much discussion among dredging experts both within and outside the Corps. Informally it was suggested that a dustpan dredge, appropriately modified, could perform as well as the Oozer Dredge in removing polluted sediments. It was further suggested that parts from retired Corps dustpan dredges, if available, could be adapted to cutterhead dredge plant. As a result of these discussions, an engineering consultant with Amalgamated Dredge Design, Incorporated, presented a proposal to the Corps. He recommended that an existing dustpan suction head and ladder, if available from a retired dredge in the St. Louis District, be modified and fitted to a contractor's cutter suction dredge. The effectiveness of this arrangement for dredging polluted sediment would then be tested and compared to the conventional cutterhead arrangement. The dredging would be accomplished as part of the maintenance of the James River Channel. This proposal was the basis for the dredging demonstration project in the James River.

DREDGING METHODS

Since most persons in the dredging business, and related activities and industries, are familiar with the various types of dredging equipment, detailed descriptions of the cutterhead and dustpan dredges and their operation will not be covered here. It is important, though, to show some of the differences between the two methods.

Cutter Suction Dredge

The James River has been economically maintained for decades by contractors with cutterhead plant. The conventional cutter suction dredge would appear to be well suited for removal of the contaminated material of the James.

The two stern spuds of the dredge, often termed the digging spud and walking spud, provide firm anchorage in the channel bottom. By rotating on the digging spud while making radial cuts across the channel, the dredge is

able to move accurately over the specified dredging area. Dredging depth and output can also be accurately controlled. Furthermore, cutter suction dredges can discharge the material over long distances, which is a distinct advantage if polluted material is to be deposited in a distant containment site.

The cutterhead dredge does have apparent disadvantages for dredging the contaminated James River sediments. The rotating cutter can cause resuspension of material at the head, particularly in the silty-clay of the James. The action of the cutter also adds water to the material in excess of the in-place water content, increasing disposal area needs if a containment site were required. Because of the geometry of the cutterhead dredging pattern, overlap of the dredge cuts cannot be avoided. These overlaps result in additional, unwanted dilution water.

Dustpan Dredge

The dustpan type dredge was developed for use in maintaining the lower Missouri and Mississippi River channels, and can achieve high outputs in granular materials. While the dustpan is a hydraulic dredging method, as is the cutterhead, it differs in how it maneuvers and excavates.

While operating, the dustpan faces into the swift river current and is held on station by two crossing headwires, anchored well upstream. The wide but shallow opening of the dustpan suction head is advanced straight ahead into the shoal and makes long cuts by hauling in the two headwires. The advantage of this method in removing polluted material is the straight line advance, permitting a constant width of cut. The dustpan dredge can also accurately control the depth of dredging.

The dustpan dredge has disadvantages for working in the James River. The dustpan head has a number of water jets at the mouthpiece which fluidize the granular material of the Mississippi River bed, permitting flow into the suction head. These jets enable high outputs of granular material, but would cause unwanted resuspension and dilution of the fine-grained sediments of the James. This soft but more cohesive material may also cause choking in the dustpan head, and may possibly spill over and around the head. Finally, additional anchor lines would be needed in the James River, where currents change direction with the tide, versus the steady current of the Mississippi.

The Problem of Total Containment

To effectively remove a layer of contaminated sediment involves a concept our consultants termed "total containment." This is more than simply dredging the sediment. The specified layer should be removed at maximum density to lessen disposal problems. Resuspension should be minimized to lessen water quality problems and the amount of contamination left behind. Ideally, no more and no less than the desired volume of sediment would be removed. It is apparent that accurate placement of the dredging equipment in the material is a necessity.

In the James River estuary, the sediments forming shoals in the navigation channel are primarily silts and clays, with relatively low densities and high

moisture contents. While this material is "easy digging" for a typical cutterhead dredge, it makes the problem of total containment more difficult.

Our consultants proposed, in essence, to combine some of the advantages of the cutterhead and dustpan methods of dredging, and eliminate some of their inherent drawbacks. The resulting dredge system would be further improved with an anchoring and maneuvering arrangement adapted from gold dredging techniques, and with advanced electronic positioning equipment.

MODIFICATION OF DUSTPAN SUCTION HEAD AND LADDER

Entry Design

The suction head on an existing Corps dustpan dredge was equipped with water jets along the top of the mouthpiece, and digging teeth on the bottom, to enhance the flow of granular material. These features are undesirable for dredging of contaminated silt, and removal of them was recommended.

Our consultants proposed fitting the dustpan (Figure 2) with a newly fabricated mouthpiece, to present a hydraulically "clean" opening to the material, without trash bars or grates. Still, the material had to overcome the entry losses of the flat rectangular mouthpiece. A rollover plate, shaped like a bulldozer blade, was recommended to accomplish this, by building up an artificial head of material at the top edge of the entrance.

The layer of material created above the head entrance would have a tendency to spill over the sides, leaving some of the specified material undredged. To prevent this, wing plates, attached to either side of the dustpan, and a splitter plate, attached in the center, were proposed. These plates were designed to provide some stability for the head as it advanced, and also to prevent the entry of dilution water at the sides.

Dredging Ladder

Modification to the existing dustpan ladder was advised for two reasons. First, the ladder required an extension to enable dredging at the greater depths of the James River. And second, this ladder needed to be modified to fit the well and trunnions of a contractor's cutter suction dredge.

ANCHORING AND MANEUVERING THE DREDGE

As well as mouthpiece design, total containment depends on the ability to accurately place and maneuver the suction head with the dredging area. This is dependent on the method chosen for wiring and anchoring the dredge.

The method proposed for the James River may appear unorthodox, but was based to some extent on mining dredging, where accurate movement and positioning is also needed. Under the proposed anchoring and maneuvering arrangement (Figure 3), the dredge would set up perpendicular to the channel center line, and make cuts across the channel between a head wire and a stern wire. The dredge would be held on station not by a spud, but by calibrated radial wires

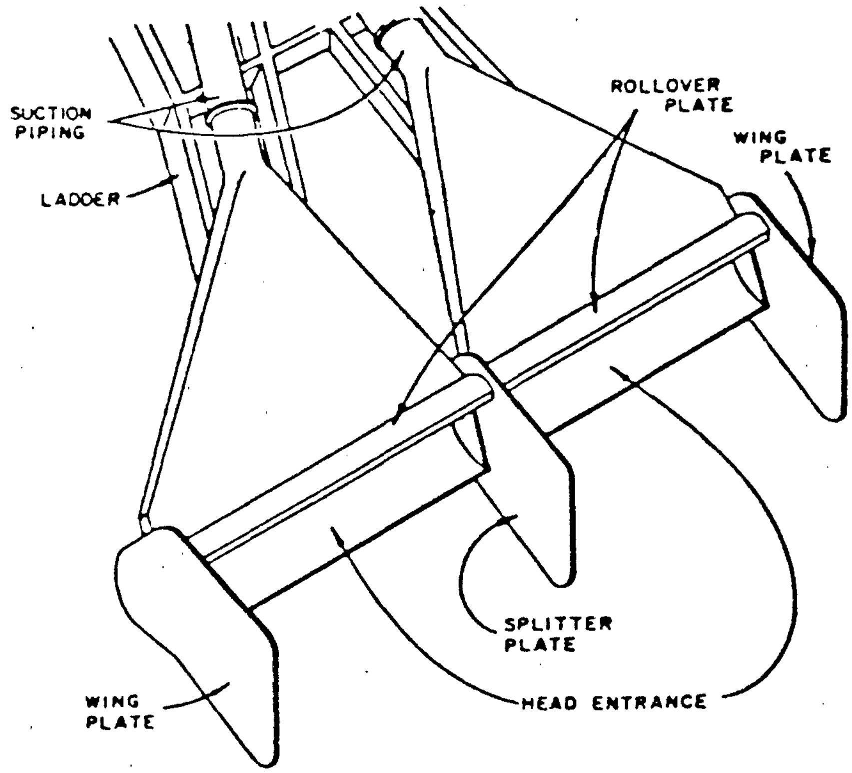

Figure 2. Modified Dustpan Head

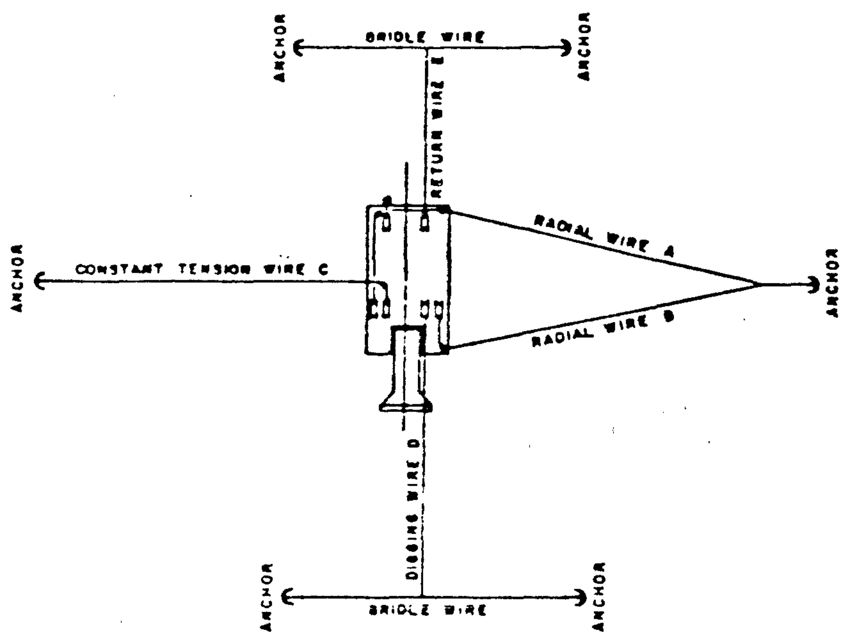

Figure 3. Wire Arrangement

anchored on the center line at a common point several hundred feet to the side. On the opposite side, our consultants recommended a wire anchored again on the channel center line, to keep the radial wires under constant tension and to enable smooth arcs across the channel.

To accurately move the dredge from one station to the next, the consultants proposed taking in an amount on the radial wires equivalent to the width of the dustpan head, and adjusting the tension wire. The resulting dredged pattern would be a series of smooth arcs across the channel. Overlap of the cuts would be minimal because of the length of the radius.

INSTRUMENTATION

The instrumentation recommended by our consultants fell into two broad categories: equipment for positioning and tracking the movement of the dredge head, and equipment for measuring and assessing the performance of the dredging system.

The first group included an electronic positioning system comprised of a three range navigation system, data processor, plotter, left/right indicator, and input/output terminal; and a ladder depth indicator with radio-transmitted tide correction. The navigation system would aid in accurate horizontal positioning and tracking of the dredge, while the ladder depth indicator would permit precise vertical placement of the dredge head.

The second group included transmitters and electronic indicators for pump vacuum and pressure and for discharge line velocity and density; a production calculator to measure output by integrating density and velocity; and a system for sampling and measuring turbidity around the dredge head. Our consultants also recommended the recording of other parameters that could be read on existing gauges, such as engine speed and engine temperature.

PROJECT IMPLEMENTATION

Environmental Coordination

Since discovery of the Kepone problem in 1975, all dredging projects within the lower James River basin have required special consideration. At first it was believed that disposal in upland containment areas would be the best disposition for Kepone-laden dredged material. State and Federal environmental agencies eventually adopted a policy that recommended open water disposal whenever feasible. Several reasons accounted for this change. Since historically the method of overboard disposal was used for most of the James River maintenance dredging, upland sites were generally not available near the Kepone contamination. Officials could not justify the tremendous expense of developing and using new upland sites for maintenance dredging requirements, which account for but a small percentage of the Kepone present in the river. Fears that Kepone deposited in upland sites would contaminate groundwater and be introduced to the upland food chain provided further impetu toward a policy of open water disposal.

During early 1981 the Corps presented the James River Dredging

Demonstration to State and Federal environmental officials. The project was proposed not as a "cleanup" effort, since open water disposal would be used, but rather as a demonstration of a potential cleanup technique. The agencies endorsed the project concept, some enthusiastically, and during the spring and summer of 1981, they met with the Corps to work out final details. Extensive water quality monitoring by both the State and the Corps was an important part of the plan.

Design Phase

A contract for architect-engineer services was awarded to Amalgamated Dredge Design, Incorporated, to prepare plans for the project and to act as chief consultants. The plans primarily involved design of modifications to the dustpan head and ladder, modifications to an existing cutter suction dredge, choice of onboard dredge instrumentation, and a program for carrying out the dredging tests.

Visits to the retired Corps Dredge KENNEDY were made to determine which dustpan parts could be made available for the project. The St. Louis District assisted by removing and delivering the specified parts to Norfolk, including the dustpan head and dredging ladder.

The designs could not be final until after it was known which cutter suction dredge would be used. The Corps received bids from four firms for lease of a dredge, and the low bidder, Norfolk Dredging Company, was awarded the dredging contract. The 18-inch (450-mm) cutter suction dredge ESSEX was designated.

During the design phase we also initiated procurement of the recommended instrumentation packages. For horizontal positioning, the contractor ordered a Tellurometer model MRD-1 three range navigation system and Digital Design & Development model PSS-1 data processing system. For vertical positioning of the dredge head, an Observator model MK-22 ladder depth indicator with tide correction was ordered. The dredge process instrumentation included IHC Holland transmitters and indicators for pressure, vacuum, velocity, and density, with a production calculator.

Maintenance Dredging

Restoration of the James River Channel would involve the removal of about a million cubic yards (756,000 cu m). We realized that the dredging demonstration effort could accomplish only a portion of this. Because of time limitations, the bulk of the dredging would need to be done conventionally. And conventional dredging could be accomplished before completion of plans for the demonstration and actual modification of the dredge, while waiting for delivery of essential instrumentation.

During November 1981 Norfolk Dredging Company removed 613,500 cubic yards (470,000 cu m) from the channel in the vicinity of Jamestown Island, using the ESSEX. The Corps and the State Water Control Board monitored water quality during this dredging, and found that Kepone levels remained within safe limits, both in the water and in shellfish. Dissolved Kepone did not exceed

9 parts per trillion, well within the water quality guideline of 15 parts per trillion.

Modification of Dredge

With final modification plans, Norfolk Dredging Company put the ESSEX into Colonna's Shipyard in February 1982 (Figure 4). The dustpan parts were reassembled, and the new mouthpiece installed. After extension of the ladder and modification of the suction piping, the dustpan was fitted in the well in place of the existing cutterhead ladder. Meanwhile, the anchor wire arrangement was altered to permit the new mode of operation.

A gantry on the dustpan head was installed to support turbidity sampling tubes. These tubes fed through a manifold to a pump for filling the turbidity test tank on the starboard deck. In the lever room, technicians began setting up instrumentation for positioning and output measurement.

Dustpan Dredging Tests

During April 1982, Colonna's Shipyard completed work on the ESSEX. We still lacked some of the instrumentation being shipped from Europe, but the decision was made to mobilize and start testing the dustpan configuration. The final items to complete the instrumentation package were the velocity and density transmitters, which were received, installed, then made operational during the first week of May by the suppliers service engineer. The dustpan dredging tests were conducted by Norfolk Dredging Company with the continuous support and advice of the engineers with Amalgamated Dredge Design, during the period April 13 through May 15, 1982. Approximately 69,000 cubic yards (53,000 cu m) was removed from the channel using the dustpan configuration and operating only during a 10-hour daylight period.

Cutterhead Dredging and Tests

Norfolk Dredging Company towed the ESSEX to their yard after completion of the dustpan tests, and replaced the dustpan head and ladder with the original cutterhead and ladder. The dredge wiring and anchor systems were also rearranged for cutterhead operation. Upon completion of this restoration work, the ESSEX was again mobilized to the James River, this time for testing of the cutterhead mode of operation and removal of the remaining shoals. Our consultants again took readings of turbidity around the head, and of vacuum, pressure, velocity, and density. The dredge contractor operated the ESSEX on a normal 24-hour day, with the exception of the 10-hour daylight period for testing and monitoring. Approximately 387,000 cubic yards (296,000 cu m) was removed between May 25 and June 15, 1982, with the dredge operating as a conventional cutterhead.

Water Quality Monitoring

During the periods of test dredging, both dustpan and cutterhead, we again conducted an extensive water quality monitoring program. Kepone and turbidity levels stayed within acceptable limits, and the effects of the disposal operation were confined to the open water disposal area. The dredging

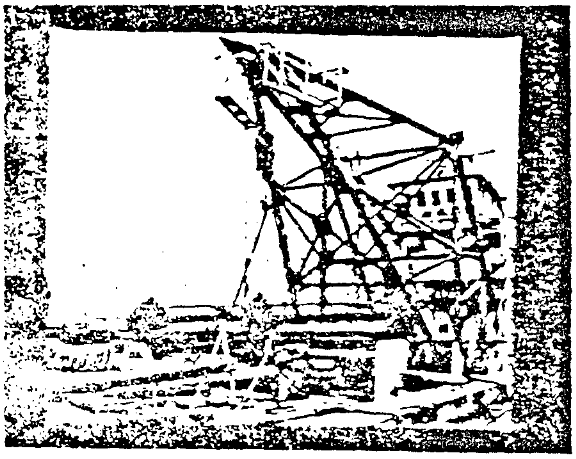

Figure 4. Dredge in Shipyard

tests provided an opportunity for the Waterways Experiment Station (WES) to conduct independent studies of the effects of the dustpan and cutterhead configurations on suspended solids levels. The State Water Control Board did not monitor during the dredging operations, but did sample to determine Kepone concentrations in the disposal areas after completion of dredging.

RESULTS OF DEMONSTRATION

Dustpan Tests

Norfolk Dredging Compan s crew in cooperation with Amalgamated Dredge Design handled the setup and operation of the ESSEX in the dustpan mode efficiently and professionally. Crew training in this unfamiliar arrangement took place onsite during the f'rst ten days and included maneuvering tests. The wiring and anchoring arran nt satisfactorily kept the dredge on station, once the crew became proficient and problems were worked out. These problems included anchor and winch brake slippage, and the stern wire catching on the pontoon line.

The success of the anchoring arrangement enabled accurate placement of the head from one cut across the channel to the next. This was desirable in trying to achieve "total containment" of polluted material. Our consultants believe the overlap between cuts was kept within acceptable limits of 3 feet (1 m) as compared to the width of the head of 28 feet (8.5 m).

Even with accurate pacement, the dustpan head was not able to contain the material as well as we had hoped. At the slowest speed of advance (7.7 feet or 2.3 m per minute) with a 9-inch-deep cut (23 cm) some material spilled over the head, creating turbidity. Our consultants believe this problem resulted from the poor hydraulic radius of the dustpan head and resistance to flow of the silty-clay. These conditions also contributed to occasional choking of the head. Average production was 300 cubic yards (230 cu m) per hour of operation.

Cutterhead Tests

With the ESSEX refitted to operate in the cutterhead mode, the contractor completed the dredging tests without significant problems.

Turbidity readings from sampling points at the suction head showed the cutter created significantly less resuspension than the dustpan. WES data confirmed this, showing a cutterhead plume in the channel averaging 10 mg per liter less than the dustpan plume. Density and output were more consistent and higher in the cutter mode than in the dustpan mode.

Throughout the final phase of cutterhead dredging, overall production was high, averaging more than 700 cubic yards (535 cu m) per hour. The contractor and consultant both attribute this to the relatively ideal conditions: soft material, good weather, and a pumping distance to the disposal area of only 2,000 feet (600 m). We believe this is also an indication of the "can-do" attitude of the contractor, and the dredging industry in general, as well as the efficiency of the conventional cutterhead d edge.

Comparison of Dustpan and Cutterhead

With any comparison of the two modes, we must keep in mind that the dustpan was modified in an attempt to contain polluted sediment, and that maximizing production during this phase was not a primary goal. This is in contrast to the cutterhead phase, where the dredge was operated efficiently and conventionally.

It was no surprise, then, that the cutterhead mode achieved higher production. During hours of operation (10 hours per day with dustpan, 24 hours with cutter) the cutter suction mode averaged more than double the production of the dustpan, on an hourly basis. Contrary to our anticipations, though, the dustpan also did not perform as well as the cutterhead in limiting resuspension at the head. Both our consultants and the Waterways Experiment Station observed higher levels of suspended material at the dustpan than at the cutterhead.

Water Quality Monitoring

The Norfolk District obtained valuable water quality data during each phase of the James River dredging. A team consisting of survey technicians, boat operator, scientists, and engineers sampled water for various parameters around both the dredge and the discharge point. The use of a survey vessel with electronic positioning enabled the samples to be taken at predetermined, known locations.

Our monitoring plan concentrated on Kepone and turbidity. Neither of these parameters increased significantly above background in the water column around the dredge head, for either dredging method. The situation differed at the disposal area. While levels of turbidity and suspended solids in this area were similar, but slightly higher during the cutter mode, the dissolved Kepone levels for the cutterhead averaged more than three times the levels during the dustpan mode (11.7 versus 3.2 parts per trillion). This is perhaps explained by the fact that the cutterhead moved more than five times the amount of material moved by the dustpan, during more or less equal periods on the calendar. At the disposal site, Kepone and turbidity levels

remained within acceptable limits, and the elevation of these levels was short term and confined to the designated disposal area.

During the first phase of maintenance dredging in November 1981, the State Water Control Board conducted a study of Kepone levels in clams held within the disposal area. The Board's study concluded that Kepone in the shellfish rose slightly as a result of the disposal operation, but not enough to be of concern. Rather than test shellfish again during the dredging tests, the Water Board chose to sample surface sediments in the disposal areas. This study showed that sediment Kepone levels were higher after the cutterhead phase than the dustpan phase. This may be due again to the vast differences in quantities deposited during the two phases.

EFFECTIVENESS OF INSTRUMENTATION

Prior to this project we had no experience with the instrumentation used on the James River. The dredging demonstration has provided the opportunity to gain experience with and judge the effectiveness of the instrumentation packages.

Electronic Positioning System

The three-range electronic navigation system, coupled with data processing equipment and plotter, proved valuable in delineating the work area and the path of the dredge within accuracy of ± one meter. Dredge operators in the lever room could monitor the dredge head location with respect to the channel using either the plotter or a left/right indicator.

As well as providing accurate horizontal positioning of the suction head, the system could also indicate when the anchoring and maneuvering wire arrangement was functioning improperly. Slippage from the desired location would show up as a deviation on the plotter as it traced the dredge head path.

The electronic positioning system was not free of problems. Early in the testing program, our technicians determined that the system was malfunctioning, and a service engineer was called in for repair. We have learned that effective use of a sophisticated system such as this requires highly trained people for operation, monitoring, and routine maintenance of the equipment.

Dredging Ladder Depth Indicator

The ladder depth indicating system proved valuable to the dredge operator for accurate vertical positioning of the dredge head. The system measured the angle of the ladder, translated this into a depth, and corrected for the height of the tide. This freed dredge personnel from periodically reading the tide at a distant location and calculating the required depth.

One problem with the depth indicator surfaced shortly after start-up. The system was not properly correcting for the radio tide signal. The supplier's service engineer promptly adjusted the system, and for the remainder of the project no other problems occurred. Again, this indicates the need

to have trained technical people available.

Dredge Production Instrumentation

Discharge pipeline velocity, density, and output readings were provided in the level room and were some of the more valuable data obtained during the project. To the dredge operator, this additional information was of little value, since he could operate as efficiently as possible using pressure, vacuum, and engine speed gauges. However, to our consultants, readings of velocity, density, and output were essential in evaluating the dustpan and cutter modes of dredging.

After calibration and start-up of the production instrumentation, the system proved steady and reliable. Our problems with this equipment were in procurement. For any instrumentation manufactured overseas, and particularly for the density transmitter with its nuclear source, we recommend long lead times to allow for procurement approval and licensing.

SUMMARY AND CONCLUSIONS

Our dredge contractor and engineering consultants did a commendable job in starting up and executing the dredging demonstration in the James River. In the dustpan mode the wiring and anchoring arrangement worked well and provided the needed accuracy. In terms of "total containment" the dustpan head did not perform as well as we hoped. Our consultants suggest that with the dustpan's wide flat opening and poor hydraulic radius, improvement may be obtained by some means of vibration or cutting action. This would reduce the resistance to flow which caused spilling over the top and sides of the head. The consultants also suggest that a different suction head design, such as a Fruehling type head, may be better in dredging contaminated silty-clay.

The selected instrumentation proved effective both in positioning accuracy and in evaluating dredge performance. Electronic equipment for horizontal and vertical positioning of the dredge head was more valuable to the dredge operators than was the production instrumentation. Management personnel of the dredging firm believe the package providing output, velocity, and density readings could be an effective tool for evaluating dredge performance problems. For sophisticated electronic equipment of any type, it is highly desirable to have well-trained technicians available, and contracts for service and maintenance are recommended.

The water quality studies conducted during the demonstration project showed that dredging in the James River does not create problems with Kepone resuspension or turbidity. The Corps and the State of Virginia have already used our documented monitoring results in evaluating and permitting other key dredging projects in the James that would otherwise have not been possible. The District is also using the information to develop a long-term disposal solution for a badly shoaled military port facility at Fort Eustis.

Overboard disposal proved to be economical and without serious environmental effects. The total project cost, including the additional costs for dredging tests and water quality monitoring, worked out to about $3.00 per

cubic yard removed. Alternative plans such as upland disposal range as high as $5 to $10 per cubic yard. We believe that dredging managers, engineers, environmental scientists, and other individuals, who have a responsibility for channel dredging or removal of contaminated material, can benefit from the various findings of this project.

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FIELD DREDGING TEST OF SOFT MUD LAYER BY A FRONT-OPEN TYPE DRAG HEAD

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SUMMARY

This paper describes the result of a field dredging test carried out as part of a study of a method of effective removal and disposal of bottom sediments in a vast closed water area such as Tokyo Bay.

We manufactured a new type drag head that can dredge soft mud, dredging thinly and widely, in high density. We equipped a trailing hopper suction dredge (hopper capacity of 4000 m^3) with this new drag head and field tested off Chiba in Tokyo Bay. Good results were obtained.

The 5th District Port Construction Bureau manufactured a second drag head of the same type and equipped the trailing hopper suction dredge "Seiryu Maru" with it and field tested in Ise and Mikawa Bays.

FIELD DREDGING TEST (I) AT CHIBA PORT

Based on the results of model tests conducted in 1977 and 1978, we manufactured a full-sized drag head, equipped a trailing hopper suction dredge with this head, and performed a field test.

The four factors to be investigated included:

- Dredging characteristics of the drag head.
- Effects of mixing blades, a stabilizer, and a protector.
- Control of dredging depth of the drag head.
- Occurrence of muddiness.

Dredge

The dredge used in this test was a trailing hopper suction dredge "Tokushun Maru No. 1". Main specifications of "Tokushun Maru No. 1" are shown in Table 1; general arrangement is shown in Figure 1.

Test Location

Location of the field test is shown in Figure 2. The dredging area was 200 m x 1000 m. Depth in this area is 13 m on the average as shown in Figure 3, and an incline is only 0.5 0/00 in the direction of the dredging line.

Drag Head

An outline of the drag head used in this test is shown in Figure 4. The front of the drag head was a rectangle, breadth B = 2.3 m, height H = 0.5 m, and area A = 1.15 m^2.* A screen for prevention of refuse was fixed to the front, and detachable mixing blades 440 mm in diameter were installed in the

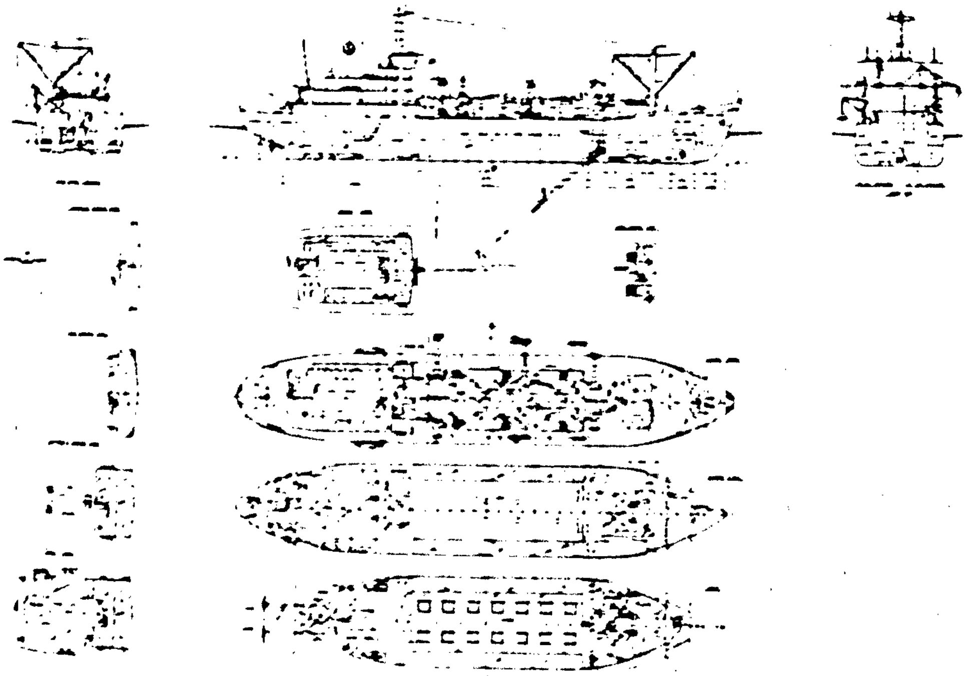


Figure 1. General arrangement

Table 1. Main specifications of "Tokushun Maru No. 1"

overall length	113.35 m	speed
l.p.p.*	106.00 m	maximum
breadth	19.60 m	cruising
depth	9.00 m	dredging
draught	6.90 m	main engine 4700 PS x 450 rpm x 2
gross tonnage	6251.21 t	drag arm side drag type 800 mm x 2
dead weight capacity	6883 t	dredging pump
hopper capacity	4691 m^3	8000 m^3/hr x 17 m x 170 rpm x 2
max. depth of dredging	27 m	swell compensator x 2

l.p.p. = length between perpendiculars.
* For convenience, a notation is provided at the end of this paper.

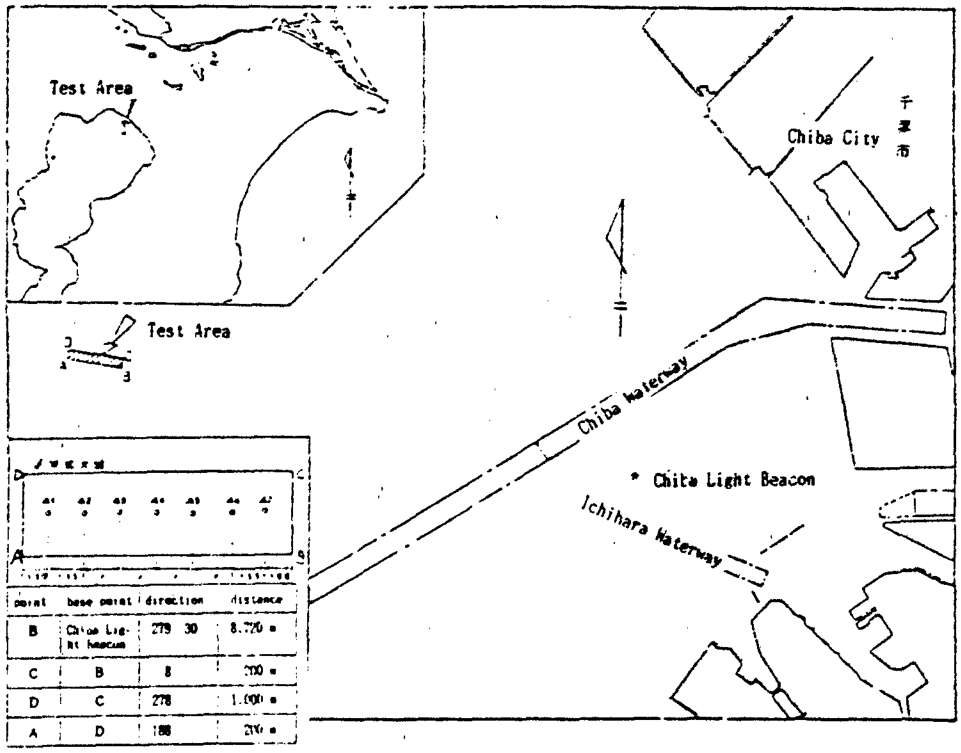


Figure 2. Location of the test

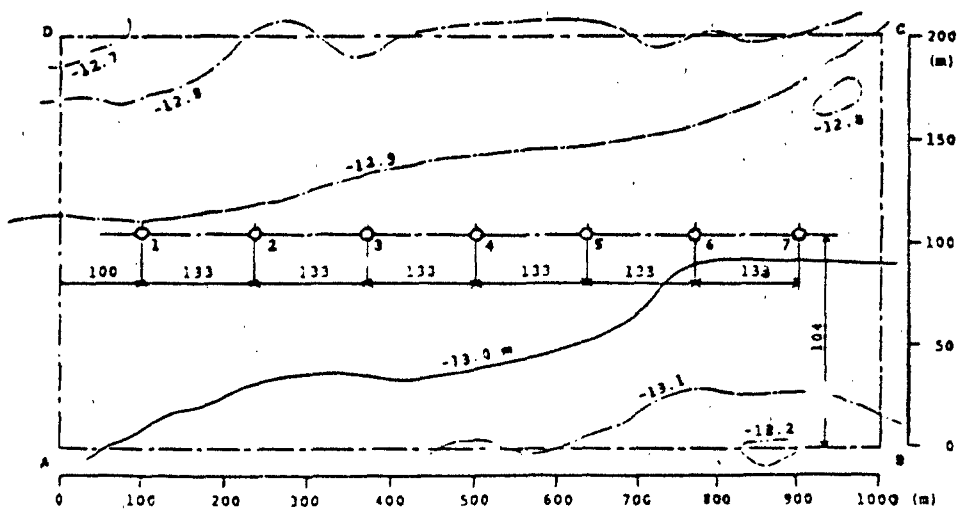


Figure 3. Depth in the test area

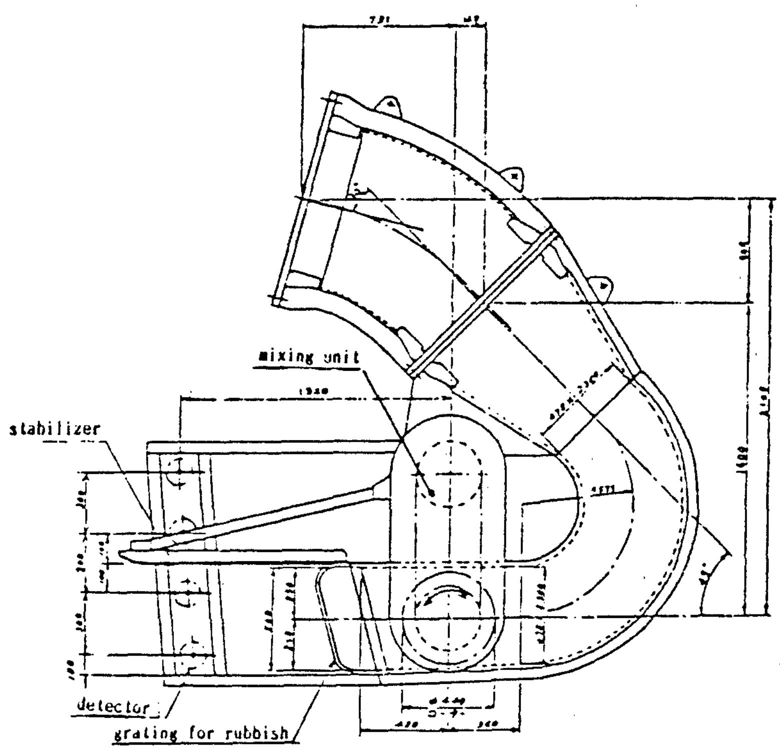


Figure 4. Drag head

drag head. A detachable stabilizer, breadth = 2.3 m and length = 1.1 m, and four sets of detectors for soft mud surface of seabed were installed on the forefront of the head. Four detachable plates 400 mm x 300 mm were attached on the sole of the head.

When the shape of the head was selected, the area and the ratio of breadth and height were the principal factors. Values of these factors were based on the results obtained by experiments with models, and we had to decide the area of the front of the head first. For this decision, the nondimensional parameter Ψ_o was an important factor. It was supposed that blockade of the suction pump occurred when Ψ_o was nearly 0.9. Therefore, Ψ_o=0.8 was selected as the design value. Other parameters were set up as shown in Table 2.

Table 2. Variables

Variable	Ψ_o	V_S	Q_o
Base value	0.8	3 kt	8,000 m^3/hr

The area of the front of the head could then be calculated from

$$A_H = \Psi_o \cdot Q_o/V_s \tag{1}$$

therefore

$$A_H = 1.15\ (m^2)$$

Since the radio of breadth to height does not severely affect the performance of dredging, the height was designed to correspond to the thickness of the Hedoro sediment H = 0.5 m (but this was the condition in 1979, and now we are going to study the technique of the thinner dredging). Consequently, breadth B was 2.3 m and the ratio of breadth to height was 4.6.

Figure 5 is an outline of the mixing blades. These blades were driven by the hydraulic motor; maximum power of the motor was 86.5 Ps/300 rpm and was driven by the hydraulic unit on board. A hydraulic circuit is shown in Figure 6.

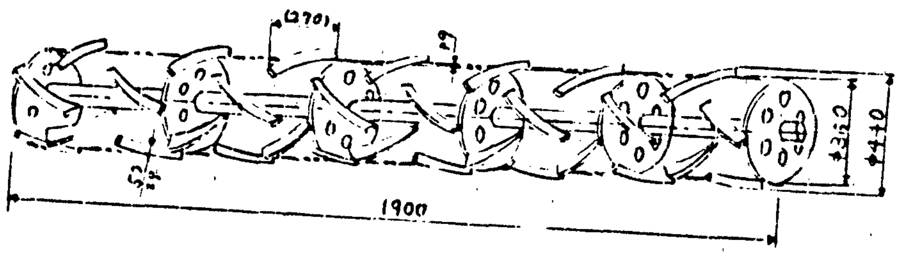


Figure 5. Mixing blades (rotor)

Investigation of Hedoro at the Location of the Test

The investigation is outlined as follows:

° The area of the investigation ..... shown in Figure 3.
° Items of the test ..... 1 release test: cyanogen, cadmium, sexivalent chrome, total mercury, lead, arsenic, organic phosphorus, PCB

2 mud quality: PCB, total mercury

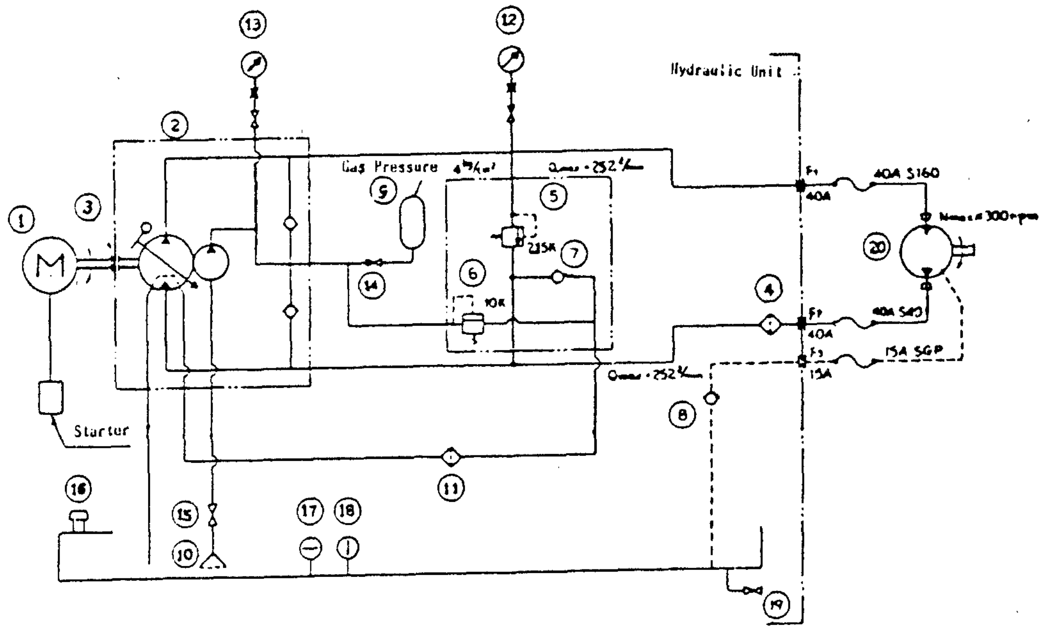
3 physical properties: specific gravity, grading, water content, consistency (liquid limit, plastic limit), vane test (undisturbed sample, disturbed sample)

Results of the investigation are as follows:

1 Release test ..... all items were nondetectable (ND) as shown in Table 3.

Table 3. Results of release test

	Sample No. No. 1	No. 2	No. 3	No. 4	Limit of Detection ppm
Alkyl mercury compound	ND	ND	ND	ND	0.003
Mercury and mercury compound	ND	ND	ND	ND	0.003
Cadmium and cadmium compound	ND	ND	ND	ND	0.1
Lead and lead compound	ND	ND	ND	ND	1
Organic phosphorus compound	ND	ND	ND	ND	1
Sexivalent chrome compound	ND	ND	ND	ND	0.5
Arsenic compound	ND	ND	ND	ND	0.5
Cyanide compound	ND	ND	ND	ND	1
PCB	ND	ND	ND	ND	0.003



No.	name	No.	name	No.	name
1	electric motor	8	lift check valve	15	sluice valve
2	hydraulic pump	9	accumulator	16	breezer
3	chain coupling	10	suction strainer	17	oil surface gauge
4	line filter	11	line filter	18	thermometer
5	relief valve	12	pressure gauge	19	drain valve
6	relief valve	13	pressure gauge	20	hydraulic motor
7	check valve	14	globe valve		

Figure 6. Hydraulic circuit

2 Mud quality ..... shown in Table 4.

Table 4. Results of mud quality test

	Sample No.				Limit of Detection ppm
	No. 1	No. 2	No. 3	No. 4	
Mercury and mercury compound	1.10	0.96	0.93	0.79	0.01
PCB	0.11	0.07	0.07	0.07	0.01

3 Physical properties ..... samples of tests were collected from the upper layer, middle layer, and lower layer of seven column samples; results of the tests are shown in Table 5.

Table 5. Physical properties

	Upper Layer	Middle Layer	Lower Layer
Cobble (%)	0.0	0.0	0.0
Sand (%)	11.2	4.3	3.0
Silt (%)	51.3	56.5	60.9
Clay (%)	37.5	39.2	36.1
Liquid limit (%)	88.4	81.6	80.2
Plastic limit (%)	53.2	46.7	45.1
Plasticity index	35.4	34.9	35.1
Specific gravity	2.664	2.709	2.733
Water content (%)	340.7	197.2	182.4
Vane test undisturbed	9.07×10^{-4}	12.26×10^{-4}	17.00×10^{-4}
disturbed	4.42×10^{-4}	4.88×10^{-4}	6.64×10^{-4}

Means of Test

Parameters of this test are as follows:

° Velocity of the ship (V_s)

° Rate of flow of the suction pump (Q_o)

° Thickness of dredging (d_H)

° Existence of the mixing blades

° Existence of the stabilizer

Cases of this test are shown in Table 6. Items of measurement are shown

Table 6. Cases of Experiment

Case	No.	velocity (kt)				rate of flow (m^3/H)		thickness of dredg.		mixing blades (rpm)			stabilizer		note
		V1	V2	V3	V4	Q1 10.000	Q2 8.000	X1 1m	X2 1.5m	Y1 0	Y2 150	Y3 300	Z1 ×	Z2 ○	
C1	1	○				○		○		○			○		V1 : 2.0kt
	2		○			○		○		○			○		V2 : 2.5kt
	3			○		○		○		○			○		V3 : 3.0kt
	4				○	○		○		○			○		V4 : 3.5kt
C2	5	○				○		○		○				○	C1
	6		○			○		○		○				○	+ stabilizer
	7			○		○		○		○				○	
	8				○	○		○		○				○	
C3	9	○				○		○			○		○		C1
	10		○			○		○			○		○		+ mixing
	11			○		○		○			○		○		blades
	12				○	○		○			○		○		(150rpm)
C4	13	○				○		○				○	○		C1
	14		○			○		○				○	○		+ mixing
	15			○		○		○				○	○		blades
	16				○	○		○				○	○		(300rpm)
C5	17	○				○		○			○			○	C1
	18		○			○		○			○			○	+ stabilizer
	19			○		○		○			○			○	+ mixing
	20				○	○		○			○			○	blades
C6	21	○				○			○	○			○		thicknss of
	22		○			○			○	○			○		dredging
	23			○		○			○	○			○		1.5
	24				○	○			○	○			○		
C7	25	○				○			○		○		○		thicknss of
	26		○			○			○		○		○		dredging 1.5
	27			○		○			○		○		○		+ mixing
	28				○	○			○		○		○		blades
C8	29	○					○	○		○			○		rate of flow
	30		○				○	○		○			○		8.000 m^3/H
	31			○			○	○		○			○		
	32				○		○	○		○			○		
C9	33	○					○		○	○			○		rate of flow
	34		○				○		○	○			○		8.000 m^3/H
	35			○			○		○	○			○		thicknss of
	36				○		○		○	○			○		dredging 1.5

in Table 7. Sounding was carried out at two places, one at the bridge (No. 18 in Table 7) used for measurement of the depth of dredging, and the other at the upper deck used for measurement of the trace of dredging. Water sampling pumps were fixed at the middle of the drag arm and at the drag head, one set of the submergible pumps at every two positions. Water was pumped up to the upper deck continuously and sampled properly. Measuring locations are shown in Figure 7 (numbers in Figure 7 correspond with those in Table 7).

Table 7. Items of measurement

No.*	Items	Means	Location	Note
1	Draught	Draught meter	Bridge	Continuously
2	Water level of hopper	Float	Hopper	At intervals of 1 minute
3	Depth of the drag head	Pressure transducer	Upper deck	Continuously
4	Pressure of the swell compensator	Pressure gauge	Bridge	At intervals of 15 seconds
5	Displacement of the swell compensator	Potentic meter	Upper deck	Continuously
6	Rolling of the vessel	Rolling meter	Bridge	Continuously
7	Rate of flow	Electro-magnetic flow meter	Bridge	Continuously
8	Density	Isotope density meter	Bridge	Continuously
9	Suction pressure	Differential pressure transducer	Pump room	Continuously
10	Discharge pressure	Pressure tranducer	Pump room	Continuously
11	Number of revolutions	Tachograph	Bridge	At intervals of 15 seconds
12	Electric current	Ampere-meter	Bridge	At intervals of 15 seconds
13	Density at trough	Water bottle	Upper deck	Once per one run
14	Turbidity around the drag head	Submergible pump	Upper deck	Twice per one run
15	Turbidity around the drag arm	Submergible pump	Upper deck	Twice per one run
16	Turbidity in background	Turbidimeter	Upper deck	Continuously
17	Position of the vessel	Electric positioning equipment	Bridge	Continuously
18	Sounding (1)	Echo sounder	Bridge	
19	Sounding (2)	Echo sounder	Upper deck	200 kHz
20	Sampling of Hedcro	Bottom sampler	Hopper	Once per one run
21	Hedoro layer	Detector	Upper deck	Continuously

* Numbers correspond to Figure 7.

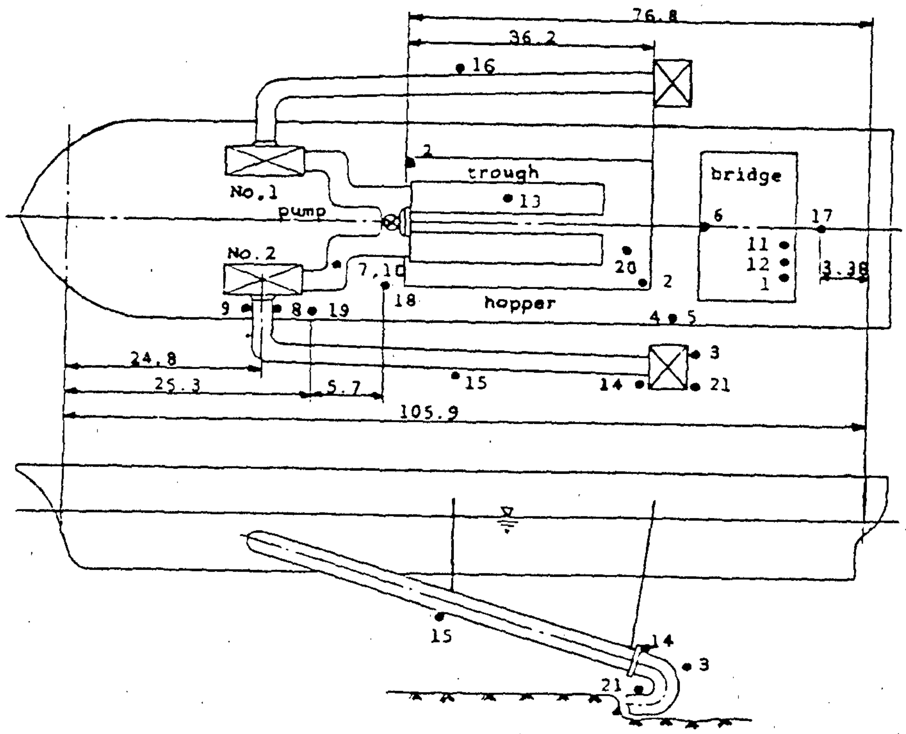


Figure 7. Locations of measurement

The term of tests was from 1 October 1979 to 6 October 1979. When considering a time schedule, we calculated the time required for each case on the basis of the volume of dredging soil, and considered a time schedule to manage cases of tests properly.

The time required per one case (which equals four runs) is

° Net dredging time ..... about 25 min/4 runs
° Turning time .... about 45 min/3 turns
° Sailing time .... distance 10 km, velocity 10 kt, therefore, about 65 min/round trip
° Dumping time .... about 25 min

The sum total is 160 min.

Consequently, the time schedule was planned as in Table 8 (1), and the time schedule was carried out as in Table 8 (2).

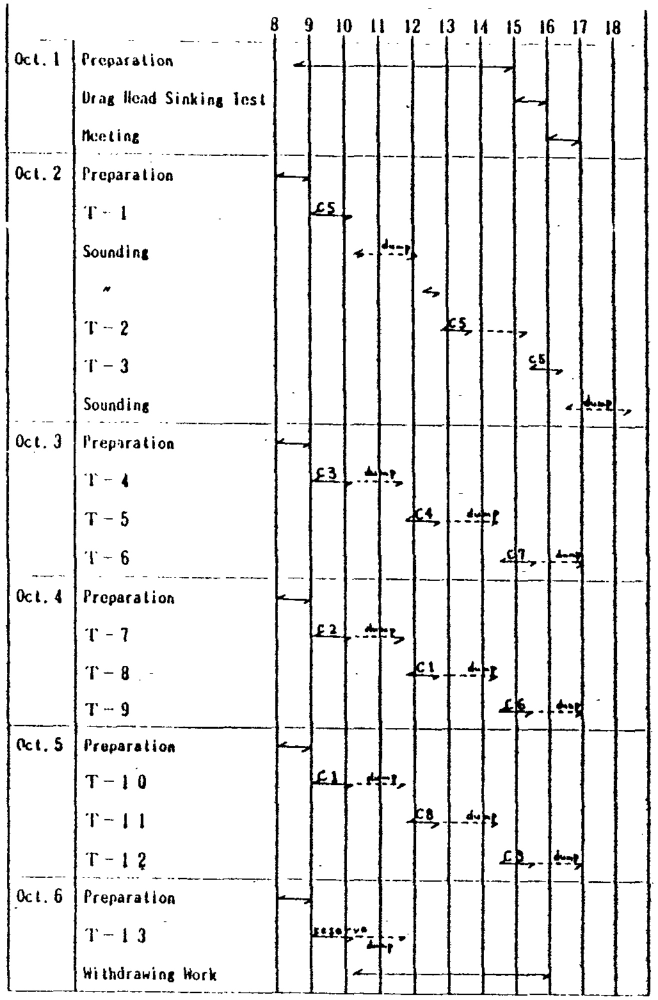
Results of Test

Marine and Meteorological Conditions

Before and after this field test, Tokyo Bay was struck by a typhoon, but it was calm during the test. Therefore, the test was conducted without hindrance. Meteorological conditions are shown in Table 9.

Table 8. Time schedule

(1) Plan



(2) Executed

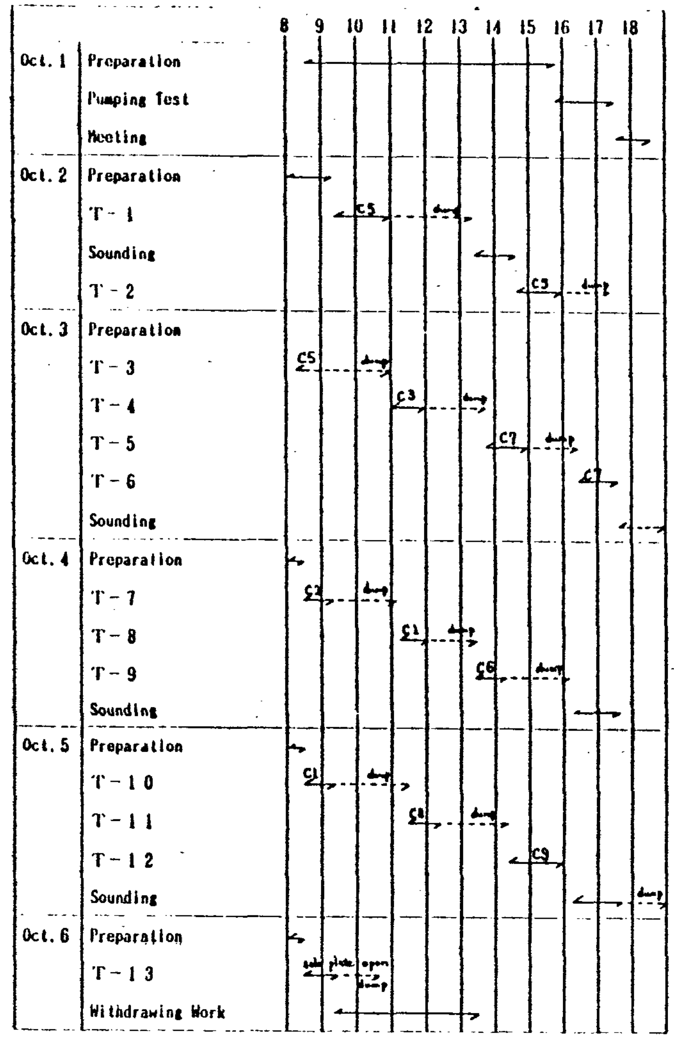


Table 9. Meteorological conditions

Date	Time	Wind Direction	Wind m/s	Weather	Atmospheric Pressure (mb)	Temperature (°C)
	8:00	SE	5	clear	992.0	28.0
10.1	12:00	SE	5	clear	995.0	28.0
	16:00	SE	5	clear	997.5	27.0
	8:00	ENE	7	cloudy	1005.0	24.0
10.2	12:00	ENE	9	rainy	1007.5	22.0
	16:00	ENE	8	cloudy	1008.0	22.0
	8:00	NNW	10	rainy	1008.5	18.5
10.3	12:00	N	5	cloudy	1007.0	19.5
	16:00	NNE	8	cloudy	1005.5	21.0
	8:00	N	4	cloudy	1001.5	20.0
10.4	12:00	N	3	cloudy	998.5	23.5
	16:00	N	2	cloudy	996.5	23.5
	8:00	N	5	cloudy	1001.0	20.0
10.5	12:00	NNE	5	cloudy	1002.0	23.0
	16:00	NE	7	cloudy	1002.0	25.0
	8:00	NE	4	rainy	1007.0	18.0
10.6	12:00	NNW	8	rainy	1009.0	17.5

Bottom Soil Condition

Soil conditions were investigated before the field test and the dredged soil was sampled from the hopper of the dredge during the field test. A grain-size distribution curve made from this sample is shown in Figure 8; the specific gravity of the soil particles was 2.63, a flow factor curve is shown in Figure 9.

Results of Field Dredging Test

Results of the test are shown in Table 10. These values are mean values during one case of the test. The contents of each data are as follows.

Furrows and velocity of the dredge. Furrows during dredging tests were obtained from electric positioning equipment and are shown in Figure 16. Velocity of the dredge, which was obtained through calculating positions of the dredge, had a mean value for 10 sec.

Depth and thickness of dredging. Thickness of dredging was obtained from a difference between depth of the head and water depth. Water depth was measured by an echo sounder and depth of the drag head was measured by a pressure gauge on top of the drag head.

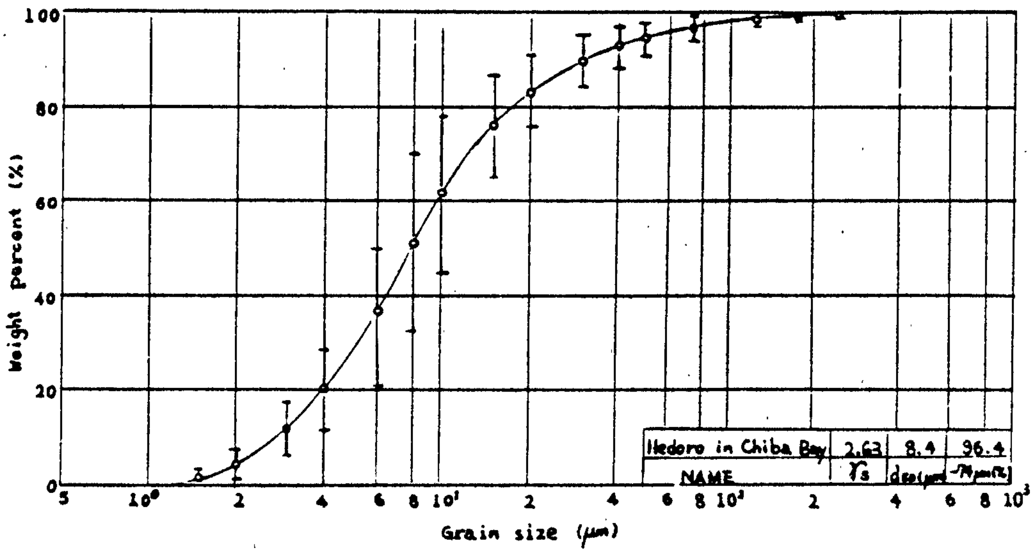


Figure 8. Grain-size distribution

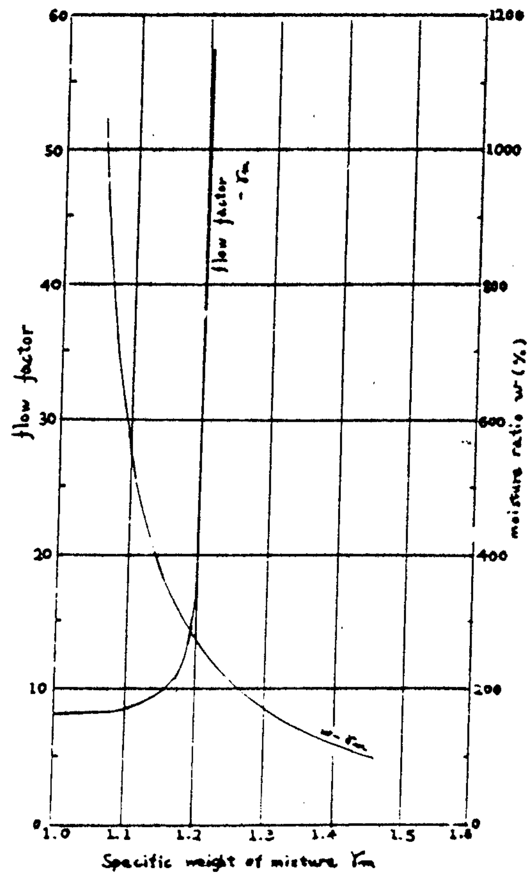


Figure 9. Flcw factor

Table 10. Results

Test No	operating condition n				continuous record				dredging time (min.)	loading volume		loa
	vel. m/s	dH (m)	Q0 m³/H	Ψ0 Qin/Q0	rate of flow m/H	density Cv (%)	specific gravity	dredging volume m³/H		contin. data 1Q (m³)	water level 1Q (m³)	conti data TQG
T1-1	1.14	0.36	9103	0.374	7903	5.3	1.110	417	9	1272	1309	140
2	1.29	0.10	9545	0.107	9561	1.5	1.049	141	7	1193	1219	125
3	1.41	0.32	9943	0.376	8744	5.9	1.120	516	4	648	270	71
T2-1	0.83	0.30	9060	0.231	8258	4.2	1.092	344	6	892	910	97
2	1.25	0.56	9372	0.551	7780	6.3	1.125	487	6	866	859	96
3	1.55	0.28	9694	0.366	6984	9.6	1.178	667	6	774	811	69
T3-1	1.66	0.23	9031	0.345	7675	6.4	1.128	494	5	716	761	80
2	1.03	0.38	9305	0.348	8047	5.6	1.115	449	5	743	707	81
3	1.54	0.28	9588	0.368	8140	6.5	1.130	531	5	744	829	83
T4-1	1.03	0.44	9050	0.414	8364	4.3	1.095	363	5	765	845	83
2	2.01	0.23	9338	0.413	8494	5.9	1.119	499	5	777	753	86
3	1.56	0.23	9626	0.309	8264	6.0	1.121	492	5	771	820	85
4	1.66	0.33	9934	0.458	9090	4.3	1.094	391	3	524	375	56
T5-1	1.39	0.66	9017	0.640	4669	12.5	1.225	582	4	403	445	47
2	1.66	0.38	9185	0.561	5842	9.3	1.174	542	4	485	476	55
3	1.33	0.58	9391	0.587	7845	7.3	1.142	570	4	600	583	67
4	1.82	0.46	9588	0.727	5956	11.9	1.216	709	6	662	686	79
T6-1	1.13	0.64	9046	0.518	7050	8.8	1.166	621	5	648	716	74
2	1.85	0.52	9276	0.827	4663	12.3	1.223	574	4	410	380	48
3	1.51	0.48	9430	0.635	4388	13.6	1.243	595	5	467	413	56
4	1.89	0.61	9602	0.815	4834	13.3	1.238	642	6	573	611	68
T7-1	1.12	0.34	9491	0.337	8722	4.0	1.089	348	4	652	639	70
2	1.15	0.32	9731	0.317	8367	6.3	1.127	530	4	638	634	71
3	1.55	0.30	9947	0.387	7403	9.1	1.172	676	4	556	518	64
4	1.92	0.38	10168	0.589	6572	10.1	1.187	662	7	862	862	100
T8-1	1.07	0.41	9501	0.380	8254	6.7	1.132	549	4	629	666	70
2	1.65	0.23	9746	0.323	8855	5.2	1.109	461	4	663	660	72
3	1.69	0.28	10000	0.390	8700	7.0	1.138	610	5	811	817	91
4	1.85	0.24	10298	0.352	9206	6.2	1.125	574	4	702	655	78
T9-1	1.08	0.64	9510	0.471	7885	8.7	1.164	684	5	721	758	83
2	1.88	0.53	9741	0.799	4474	14.7	1.261	657	6	528	503	64
3	1.11	0.61	10000	0.459	8098	9.7	1.181	788	5	746	734	85
4	1.75	0.50	10240	0.706	5578	13.3	1.239	742	7	756	731	91
T10-1	1.29	0.30	9486	0.342	8637	4.1	1.091	357	4	646	625	70
2	0.80	0.28	9731	0.191	9157	3.8	1.085	344	4	681	679	73
3	2.04	0.29	9976	0.497	8475	7.3	1.142	618	4	652	659	73
4	1.80	0.44	10202	0.637	6370	12.3	1.223	785	[illegible]	743	718	88
T11-1	1.35	0.24	8456	0.319	7336	5.0	1.106	368	5	674	711	74
2	1.73	0.28	8696	0.465	6875	7.3	1.152	542	5	650	633	73
3	1.34	0.23	8946	0.287	7172	8.8	1.167	632	5	676	674	77
4	1.78	0.19	9200	0.392	6751	9.1	1.172	617	5	657	646	75
T12-1	0.95	0.68	8461	0.465	6462	8.8	1.165	565	6	723	750	83
2	1.06	0.49	8720	0.489	5581	11.7	1.213	552	6	651	616	76
3	1.31	0.56	8960	0.604	5409	11.6	1.211	628	6	630	612	74
4	1.80	0.49	9190	0.797	4885	13.1	1.234	637	8	742	706	89
T13-1	1.59	0.52	9477	0.738	6391	11.5	1.210	736	5	633	660	74
2	2.03	0.57	9707	0.865	4803	13.6	1.243	652	7	682	643	81

Table 10. Results

	continuous record				dredging time	loading volume		loading weight		specific gravity of slerry in hopper	sea level	draught	depth
/	rate of flow m^3/H	density Cv (%)	specific gravity	dredging volume m^3/H	(min.)	contin. data 10 (m^3)	water level 10 (m^3)	contin. data 10G Ton	water level 10G Ton	γ_m	(m)	(m)	(m)
4	7903	5.3	1.110	417	9	1272	1309	1405	1444	1.104	0.84	4.77	13.9
7	9561	1.5	1.049	141	7	1193	1219	1250	1324	1.047	1.11	5.53	14.3
6	8744	5.9	1.120	516	4	648	270	718	512	1.108	1.29	6.12	14.5
1	8258	4.2	1.092	344	6	892	910	970	970	1.087	1.94	4.64	15.1
1	7780	6.3	1.125	487	6	866	859	967	982	1.117	1.95	5.19	14.8
6	6984	9.6	1.178	667	6	774	811	898	921	1.160	1.95	5.76	15.0
5	7675	6.4	1.128	494	5	716	761	800	806	1.116	0.60	4.57	13.8
8	8047	5.6	1.115	449	5	743	707	818	866	1.101	0.57	5.03	13.7
8	8140	6.5	1.130	531	5	744	829	833	917	1.120	0.55	5.55	13.8
4	8364	4.3	1.095	363	5	765	845	832	875	1.088	0.81	4.59	14.1
3	8494	5.9	1.119	499	5	777	753	861	873	1.107	0.89	5.08	14.2
9	8264	6.0	1.121	492	5	771	826	857	891	1.110	1.03	5.61	14.5
8	9090	4.3	1.094	391	3	524	375	566	546	1.081	1.21	6.02	14.4
0	4669	12.5	1.225	582	4	403	445	475	479	1.178	1.71	4.48	15.0
1	5842	9.3	1.174	542	4	485	476	552	509	1.139	1.83	4.77	15.0
7	7845	7.3	1.142	570	4	600	583	675	668	1.125	1.91	5.14	15.2
7	5956	11.9	1.216	709	6	662	686	792	834	1.195	1.96	5.56	15.3
8	7050	8.8	1.166	621	5	648	716	746	731	1.152	2.05	4.58	15.4
7	4663	12.3	1.223	574	4	410	389	484	513	1.183	2.00	4.92	15.1
5	4388	13.6	1.243	595	5	467	413	560	524	1.201	1.93	5.24	15.4
5	4634	13.3	1.238	642	6	573	611	589	745	1.203	1.85	5.62	15.0
7	8722	4.0	1.089	348	4	652	639	704	731	1.080	0.83	4.51	14.1
7	8367	6.3	1.127	530	4	638	634	711	641	1.114	0.75	4.92	14.2
7	7403	9.1	1.172	676	4	556	518	640	665	1.152	0.73	5.29	14.0
9	6572	10.1	1.187	662	7	862	862	1008	988	1.170	0.58	5.78	13.9
0	8254	6.7	1.132	549	4	629	666	703	695	1.116	0.78	4.53	14.1
3	8855	5.2	1.109	461	4	663	660	727	728	1.097	0.85	4.95	14.0
0	8700	7.0	1.138	610	5	911	817	910	936	1.123	0.97	5.43	14.1
2	9206	6.2	1.125	574	4	792	655	780	822	1.111	1.05	5.92	14.1
1	7885	8.7	1.164	684	5	721	753	830	814	1.151	1.67	4.56	14.7
9	4474	14.7	1.261	657	6	528	503	646	611	1.223	1.79	5.00	14.9
9	8098	9.7	1.181	788	5	746	734	868	847	1.164	1.89	5.43	14.9
5	5578	13.3	1.239	742	7	756	731	911	920	1.205	2.03	5.93	14.9
2	8637	4.1	1.091	357	4	646	685	701	713	1.085	0.97	4.49	14.1
1	9157	3.8	1.085	344	4	681	679	734	737	1.077	0.91	4.92	13.9
7	8475	7.3	1.142	618	4	652	689	735	732	1.127	0.85	5.33	13.9
[illegible]	6370	12.3	1.223	785	6	743	718	887	932	1.194	0.77	5.81	13.8
9	7336	5.0	1.106	368	5	674	711	741	713	1.100	0.68	4.53	13.9
5	6875	7.9	1.152	542	5	650	633	736	774	1.132	0.72	4.95	13.6
7	7172	8.8	1.167	632	5	676	674	772	814	1.142	0.76	5.39	13.9
2	6751	9.1	1.172	617	5	657	646	753	758	1.145	0.85	5.81	13.9
5	6462	8.8	1.165	565	6	723	750	830	832	1.148	1.82	4.56	15.[illegible]
9	5581	11.7	1.213	652	6	651	616	769	746	1.180	1.95	5.02	14.9
4	5409	11.6	1.211	628	6	630	612	746	683	1.185	2.08	5.45	15.0
7	4885	13.1	1.234	637	8	742	706	897	913	1.208	2.19	5.89	15.2
3	6701	11.5	1.210	736	5	633	660	744	729	1.176	1.28	4.49	14.5
5	4603	13.6	1.243	652	7	682	644	818	825	1.200	1.15	4.92	14.3

2

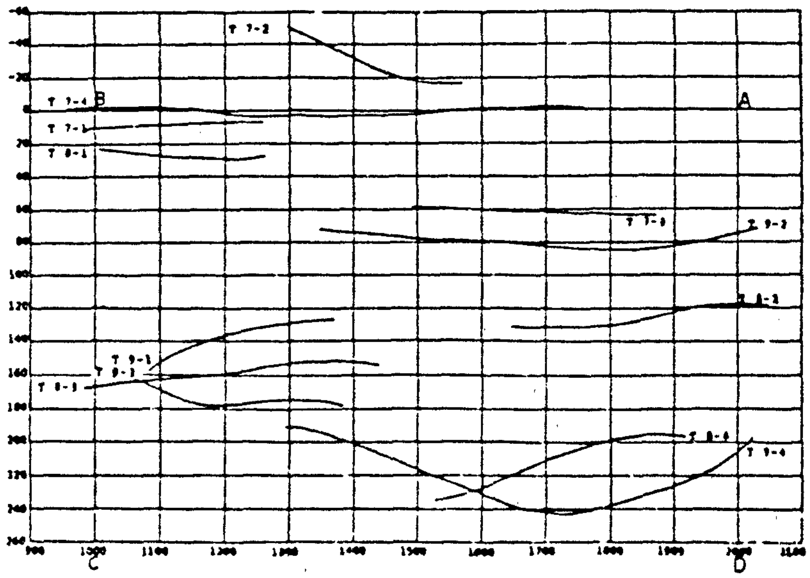


Figure 10. Furrows

After dredging started, thickness of dredging increased with increased water depth. Therefore, in this test we took the changes in draught and the pressure of a soft mud seabed surface into account, and operated the drag-head-winch in a manner to maintain the planned thickness of dredging.

Discharge of the suction pump at water supply. Actual head of a pump changes with a change in draught; this change is accompanied by a discharge of the suction pump. Results of the discharge of the suction pump measured at the field test are shown in Figure 11.

Density and rate of flow. Density of slurry in the pipe was measured by the isotope type density meter; rate of flow of slurry in the pipe was measured by the electromagnetic flow meter. These results are shown in Figure 12.

Analysis of the Results

Density and Decline of Discharge

Density and discharge flow rate are inversely proportional to each other and are determined by soil condition, characteristics of the pump, and state of dredging. Figure 13 shows the tendency of a decline of a discharge flow rate with an increase of density. In the California type drag head used for sandy soil, this decline of discharge has a tendency to be linear, and does not decline hastily as in the field test. This results from the additional resistance caused by an increase of density when a drag head is buried in soft mud as in this test. From Figure 13, an equation with respect to a decline of discharge becomes

$$Q_m/Q_o = 1 - 10.3\, C_v^{1.55} \qquad (2)$$

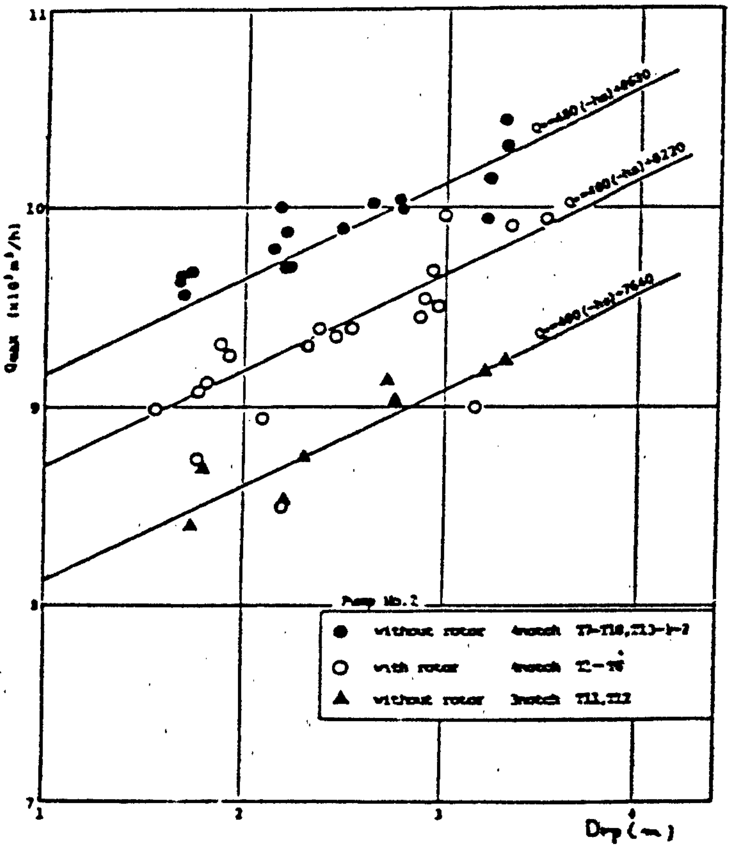


Figure 11. Discharge of the suction pump

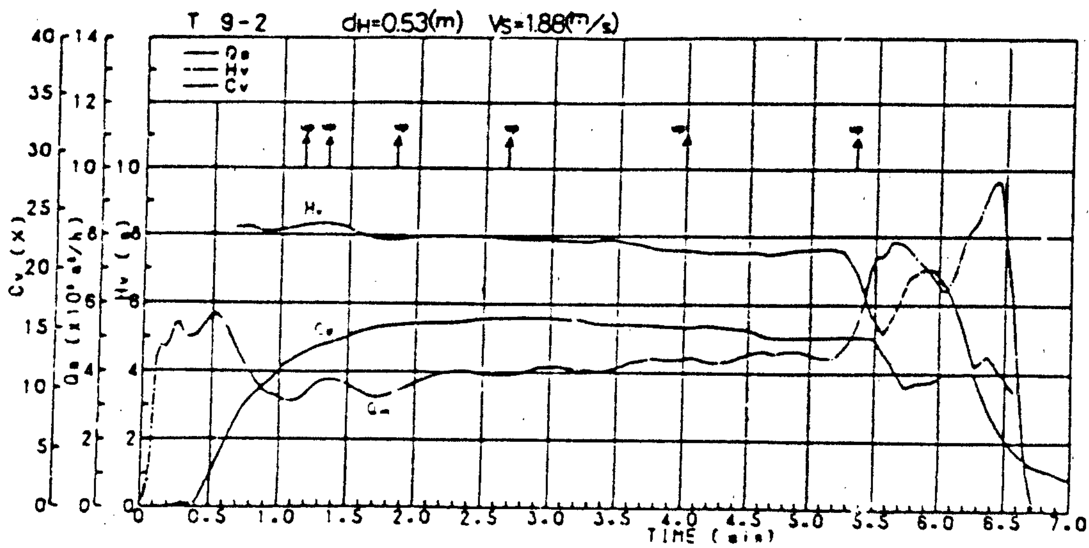


Figure 12. Continuous data

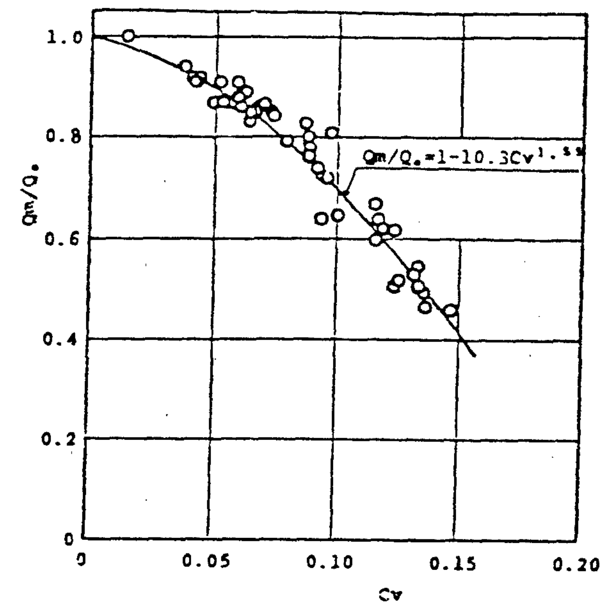


Figure 13. Rate of flow and density

On the other hand, quantity of solids dredged per unit time is written as

$$G_s = C_v \cdot Q_m \tag{3}$$

using Eq. 2, Eq. 3 is expressed as

$$G_s/Q_o = C_v(1-10.3\ C_v^{\ 1.55} \tag{4}$$

and then Eq. 4 is shown in Figure 14. From this equation, quantity of solids dredged per unit time has the maximum value when density is 12.1%, and quantity of solids dredged per unit time cannot be expected to increase over this density. This trend is confirmed in Figures 15 and 16.

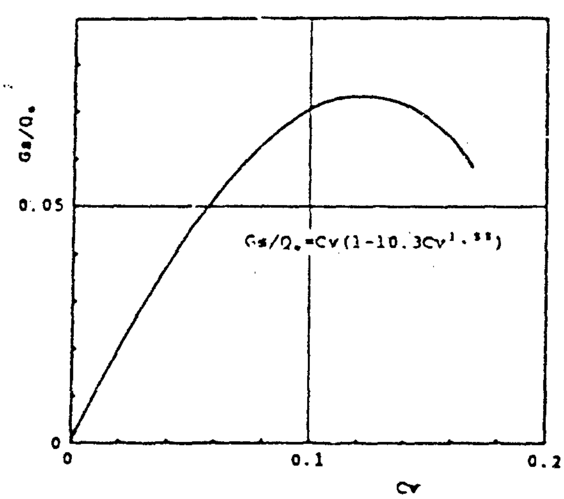


Figure 14. C_v and quantity of solids dredged per unit time

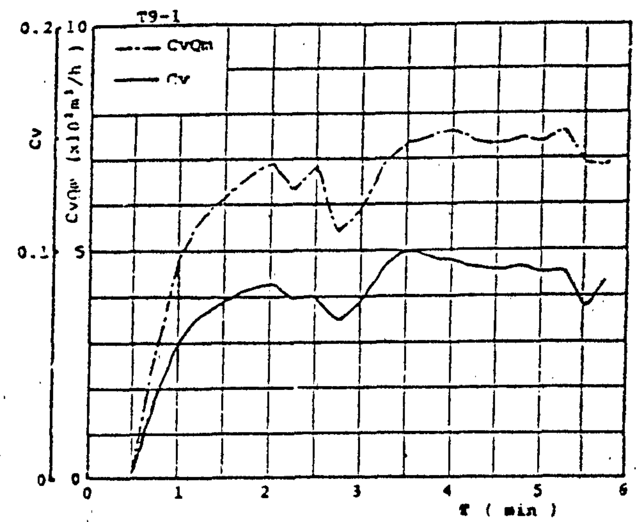


Figure 15. Density and quantity of solids dredged per unit time

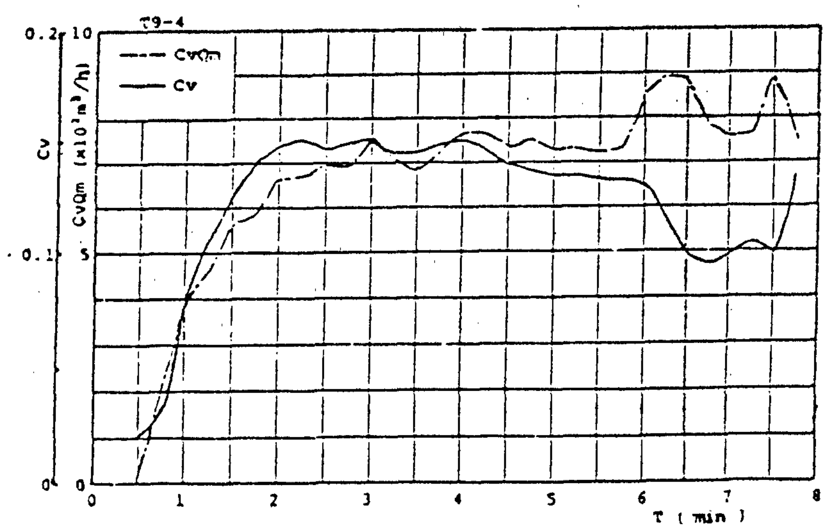


Figure 16. Density and quantity of solids dredged per unit time

Conditions of Operation and Density

In the model experiments C_v showed a comparatively large value at the smaller Ψ_o and an increase in C_v became less at the larger Ψ_o. But it was found in this experiment that C_v increased linearly up to $\Psi_o = 0.8$ as shown in Figure 17.

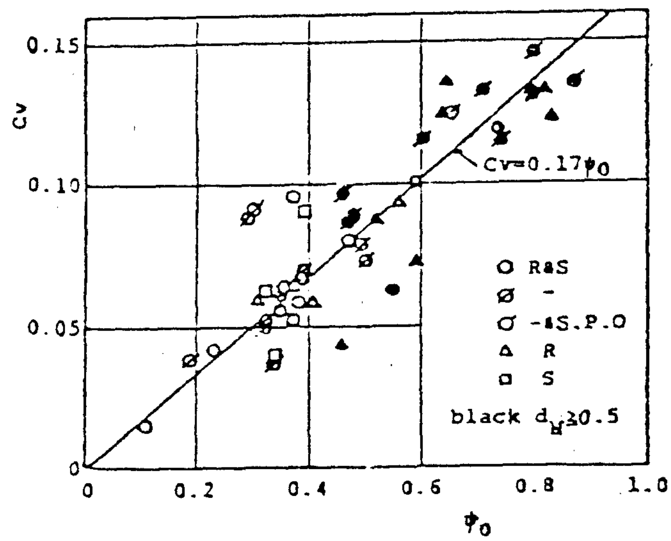


Figure 17. C_v and Ψ_o

This is expressed by the following equation:

$$C_v = 0.17\ \Psi_o \tag{5}$$

At a Hedoro water content (depth of 30 cm), apparent density becomes

$$C_a = (W_n/100) \cdot \gamma_s \cdot C_v/\gamma_w + C_v \tag{6}$$

and substituting into Eq. 6:

$$W_n = 220\%,\ \gamma_s = 2.63,\ \gamma_w = 1.025$$

then C_a becomes,

$$C_a = 6.64\ C_v \tag{7}$$

Therefore, we obtain the following equation by substituting Eq. 5 into Eq. 7:

$$C_a = 1.13\ \Psi_o \tag{7'}$$

Figure 18 shows a relation between C_a and Ψ_o. This expresses that Hedoro was dredged at fairly high density when Ψ_o was large.

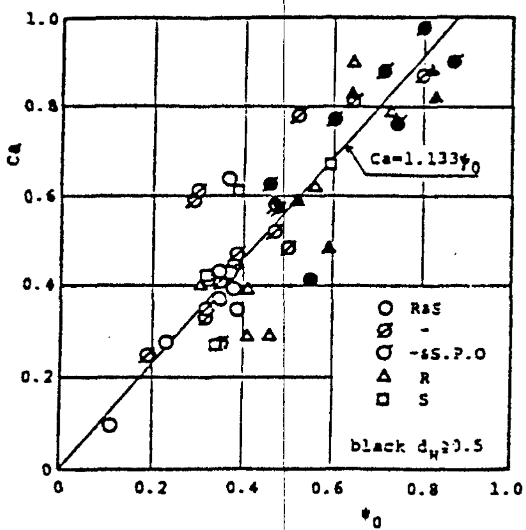


Figure 18. C_a and Ψ_o

Effect of Mixing Blades and Horizontal Stabilizer

Both the mixing blades and the horizontal stabilizer increased the added resistance when the drag head was not buried, but when it was buried mixing blades caused a decrease in resistance. This suggests that mixing blades can improve the blockage condition of the drag head.

It is important to note that liquidity of Hedoro in this test area was too low to have a flow factor but the blockage, which occurred in the model experiments, did not occur. Because the blockage did not occur, the ratio of the cross-sectional area of the suction pipe of the drag arm to that of the inlet of the drag head was remarkably improved. It is important that the proportion of a geometrical shape of a drag head be well balanced.

Change of Quantity of Solids Dredged
per Unit Time and Remnant of Dredging Soil

The quantity of solids dredged per unit time is fixed by the combination of a decrease of the rate of flow and increase of density; therefore, Eq. 3 is rewritten as

$$G_s = C_v \cdot \frac{Q_m}{Q_o} \cdot Q_o$$

and substituting Eq. 2 and Eq. 5 into this equation, we obtain

$$G_s/Q_o = 0.17\ \Psi_o\ (1 - 0.661\ \Psi_o^{\ 1.55}) \qquad (8)$$

Therefore, quantity of solids dredged per unit time has the maximum at $\Psi_o = 0.714$. This result indicates that production of the dredge is optimized at this point.

Another factor is the amount of material presented to the drag head that is not removed. Now taking the ratio of quantity of Hedoro forcibly sent into the head to quantity of Hedoro actually dredged, we make it $1/\varepsilon$ as

$$1/\varepsilon = (Q_{IN} \cdot C_B) / (C_v \cdot Q_m) \tag{9}$$

From $W_o = 220\%$, then $C_B = 0.15$, and arranging experimental data, we obtain Figure 19. Judging from this figure, we find that the drag head cannot remove all the material presented to it when C_o is greater than 0.4. It is necessary for us to investigate how this remanant affects the appearance of muddiness.

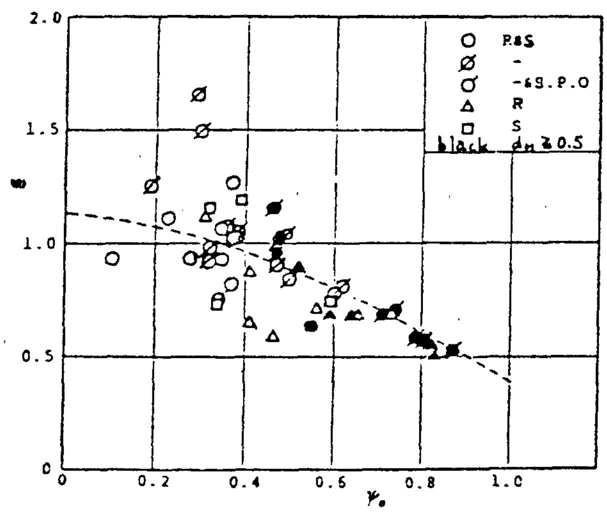


Figure 19. ε and Ψ_o

Depth Control of Dredging

Depth of dredging is usually controlled by a swell compensator. The drag head follows the sea bottom by controlling air pressure of the swell compensator, using bearing capacity. But we could not expect bearing capacity of Hedoro in this test and many unknown factors existed such as buoyancy and bearing capacity acting upon the bottom plate of the drag head when the drag head was buried, etc. Therefore, we decided to control the depth of dredging by winch operation instead of swell compensator.

In this test, we first measured the water depth with the echo sounder; second, we set up the position of the drag head by adding thickness of dredging to the depth; and, third, we wound and rewound the winch properly by considering continuous measuring data on dredging conditions (for example, water depth, draught, density, and detector for soft mud seabed surface). These results are shown in Figure 20. The example without winding the winch is shown in Figure 21, when the drag head was buried.

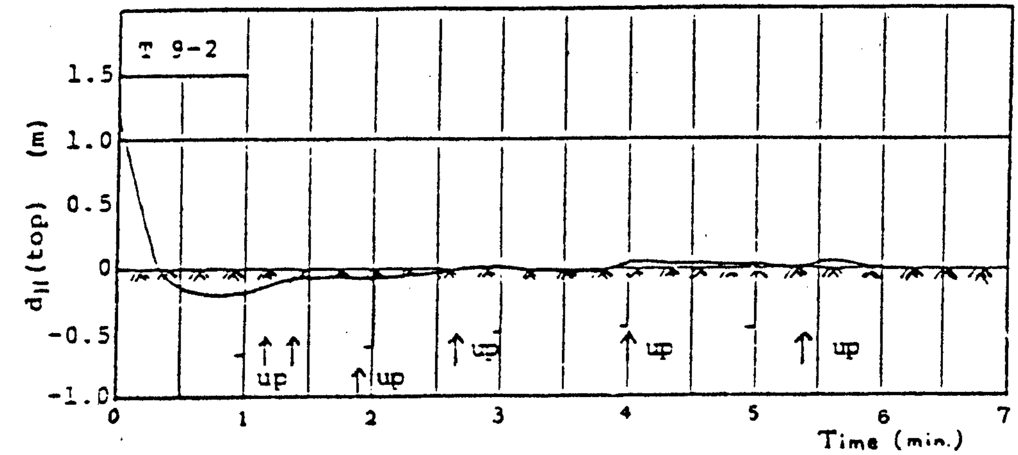


Figure 20. Thickness of dredging

This operating method is practical where the sea bottom has gentle undulations as in this test, but when the sea bottom has ragged undulations, it is very difficult to follow the sea bottom by hand operation of the winch. Therefore, it is necessary to establish a technique for automatic operation.

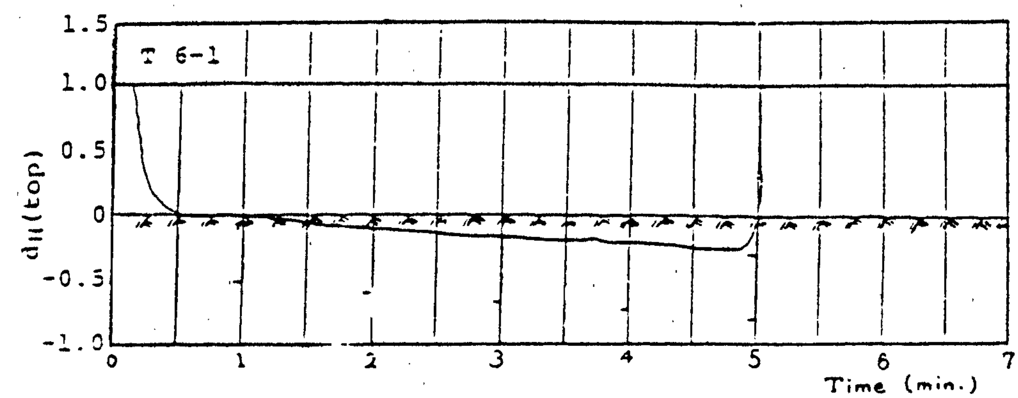


Figure 21. Thickness of dredging, buried drag head

Turbidity Caused by Dredging

All samples taken by the submergible pump at the middle of the drag arm had suspended solids (SS) values under 15 mg/ℓ and turbidity was nonexistent. Samples taken by the submergible pump at the drag head had SS values mostly under 10 mg/ℓ, but a few of the samples showed considerably higher values. Table 11 shows SS density values recorded over 30 mg/ℓ.

Table 11. Examples of turbidity

Test No.	SS (mg/ℓ)	Sampling Time M	Sampling Time S	Up or Down	Winching Time M	Winching Time S	d_H (m)	V_s (kt)
T 5-4	130	1	00	↑	1	00	0.46	3.63
T 6-2	600	3	00	↑	3	00	0.52	3.59
T 6-3	2500	2	30	↑	2	30	0.48	2.93
T 6-4	8400	2	30	↑	2	30	0.61	3.67
	4600	1	00	--	--			
T 9-2	6300	3	00	↑	2	40	0.53	3.65
	320	5	00	↑	5	20		
T 9-4	300	2	30	↑	2	30	0.50	3.40
T12-4	40-60	--		--	--		0.49	3.53
	3400	2	30	↑	2	30		
T13-2	1300	4	30	↑	5	00	0.58	3.94

From Table 11 it can be said that:

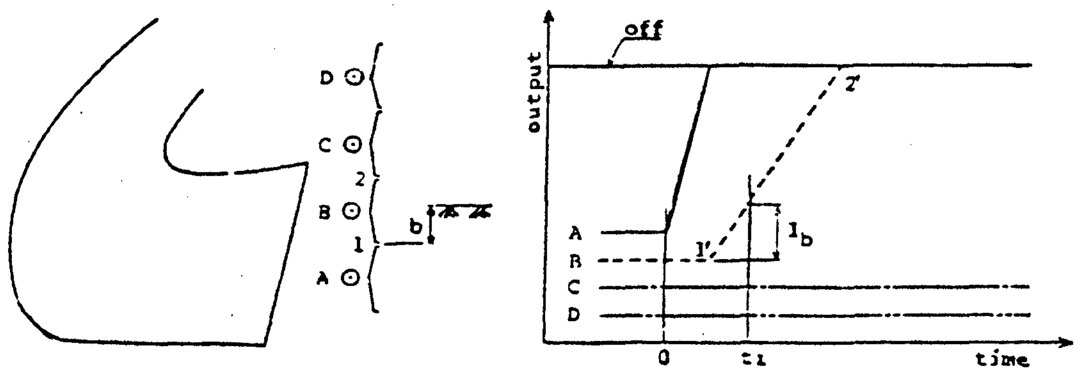
a. Very high SS occurrences coincided with operation of the winch.

b. High SS occurred only when the thickness of dredging was over 0.5 m (the drag head was buried) and speed of the ship was high.

Judging from these trends, it is possible that, when the dredging parameter Ψ_o is large, the remnant of dredging soil occurs in front of the drag head, rises up on the upper surface of the drag head, and is diffused by the winding operation of the winch.

Detector for Soft Mud Seabed Surface

In this test, we manufactured detectors for soft mud seabed surface by measuring attenuation of an ultrasonic wave. Four pairs of transducers were used, of which one pair consisted of a transmitter and a receiving oscillator 1 m distant from each other. Attenuation of an ultrasonic wave between a transmitter and a receiving oscillator was continuously measured, and from the data of attenuation we detected the existence of soft mud. A receiving level does not actually change linearly between two neighboring pairs, but we simplified as in Figure 22 to calculate linearly. Figure 23 shows the comparison between the result of the above calculation and that of the depth of



$b = kl_b$ (when $t = t_1$)

Figure 22. Method of calculation

the drag head. From these results, the detector showed the wrong information when Ψ_o was large (velocity of the ship had an important effect in this case), because a soft mud surface in front of the drag head was built from the unentrained soil and turbidity appeared. But when the ship (dredge) sailed slowly, the detector showed the comparatively correct information.

Remaining Tasks

Dredging Performance Near Blockage Boundary

We could not obtain the characteristics near the blockage boundary from the condition of this test. So we could not confirm whether or not the characteristics obtained from the model experiments could be applied to a full-sized drag head. Therefore, an experiment in Hedoro of low water content is needed.

State of Turbidity

We sampled water by a submergible pump installed upon the drag head in order to measure turbidity around the drag head. This revealed the basic characteristics of turbidity, but it was impossible to analyze the distribution of sediment resuspension and the mechanism of occurrence of turbidity quantitatively. Therefore, it is necessary to conduct experiments using many water sampling pumps and TV cameras, etc., to analyze and observe the state of turbidity.

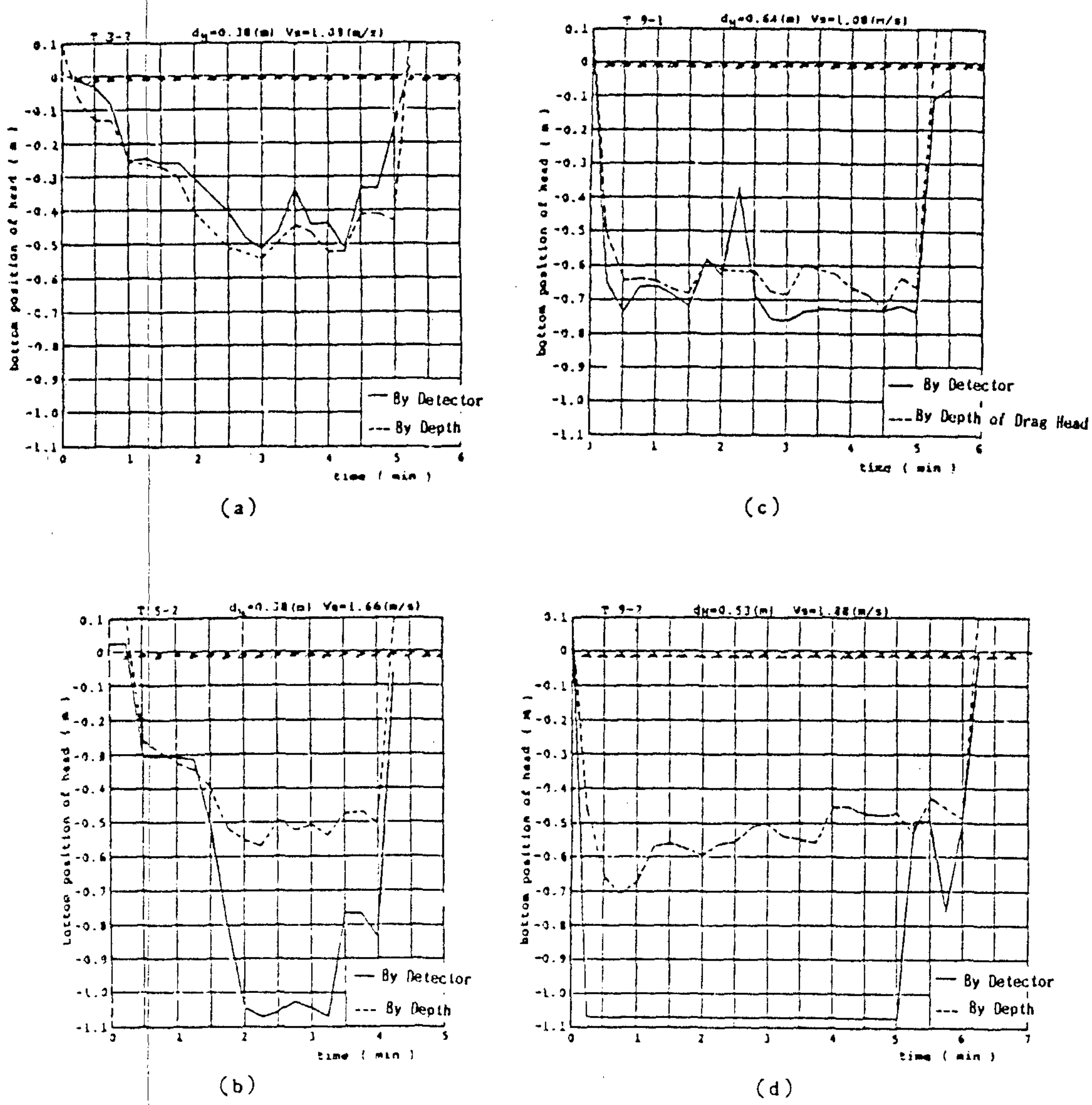


Figure 23. Depth of the drag head

FIELD DREDGING TEST (II) AT NAGOYA PORT

A field dredging test at Nagoya Port by the trailing hopper suction dredge "Seiryu Maru" was carried out in February 1981, following the field dredging test (1) in 1979.

The factors investigated in this test were fundamentally the same as that of the test in 1979, but since we manufactured a new drag head for "Seiryu Maru" use, the factors are arranged as follows:

- Characteristics of dredging by "Seiryu Maru"
- Characteristics of dredging of Hedoro in low water content

Dredge

The dredge used in this test was the trailing hopper suction dredge "Seiryu Maru"; main specifications are shown in Table 12.

Table 12. Main specifications of "Seiryu Maru"

Overall length	94.9 m	Maximum speed	13.3 kt
Lp.p.	88.0 m	Dredging speed	6.33 kt
Breadth	16.0 m	Main engine 3000PS x 400 rpm x 2	
Depth	7.2 m	Dredging pump 4100 m^3/hr x 17 m x 450KW x 2	
Draught	5.6	Drag arm 620 mmd side drag type	
Gross tonnage	3526 GT	Swell compensator	
Dead weight capacity	3202 t	Bow thruster c.p. propeller	
Hopper capacity	1754 m^3	300KW x t	
Max. depth of dredging	22 m		

Test Location

Location of this field test is shown in Figure 24. The dredging area was 200 m x 780 m.

The sea bottom in this area was sounded before dredging. A part of the depth is shown in Figure 25. The sea bottom in this area is considerably uneven due to previous dredging.

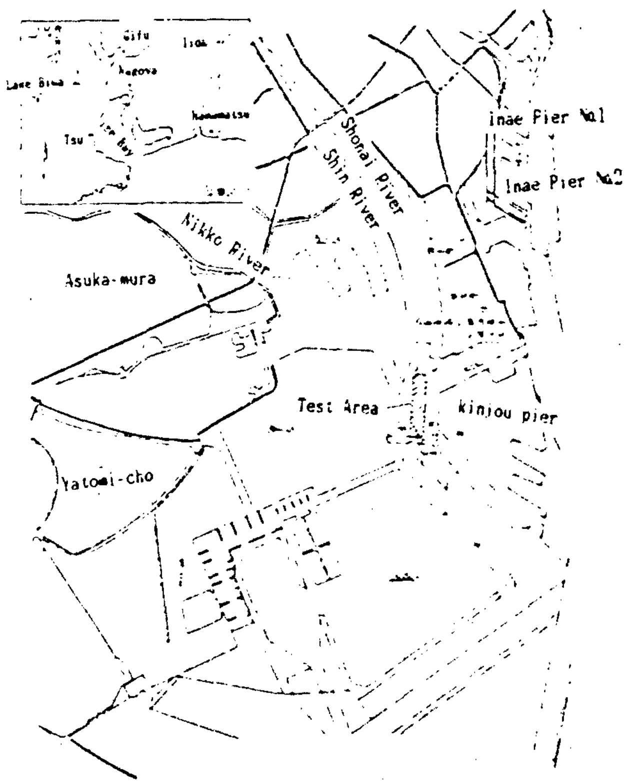


Figure 24. Location of the test

Drag Head

An outline of the drag head used in this test is shown in Figure 26. It is a front open type with the front of the drag head shaped in a rectangle, breadth B = 1.8 m, height H = 0.4 m. Fundamentally, this is the same structure as that of "Tokushun Maru."

Bottom Soil Conditions

The fluidity of the bottom was so low that the soil could not flow out by its own dead load at the flow test; i.e., the flow factor was infinite.

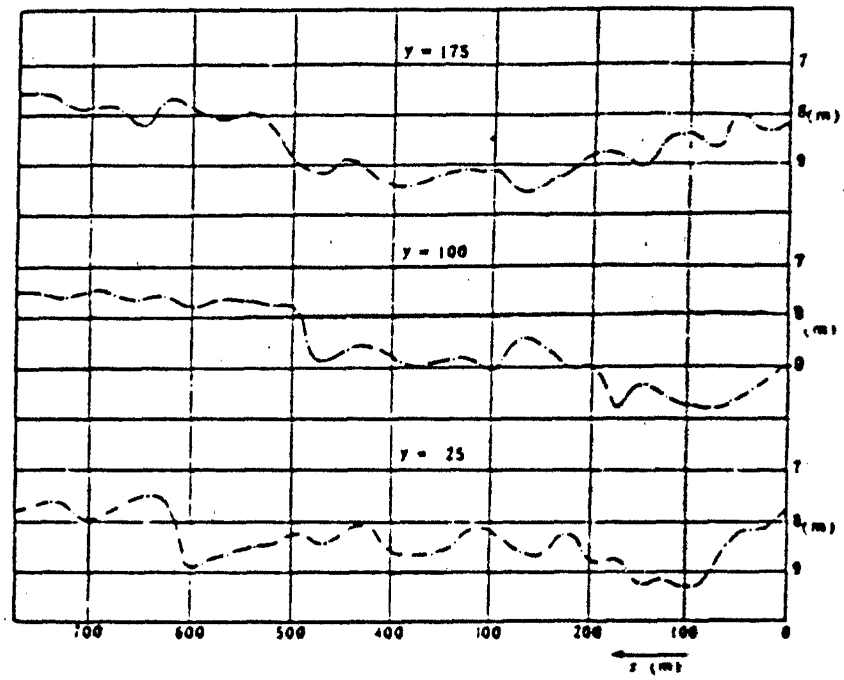


Figure 25. Sounding data

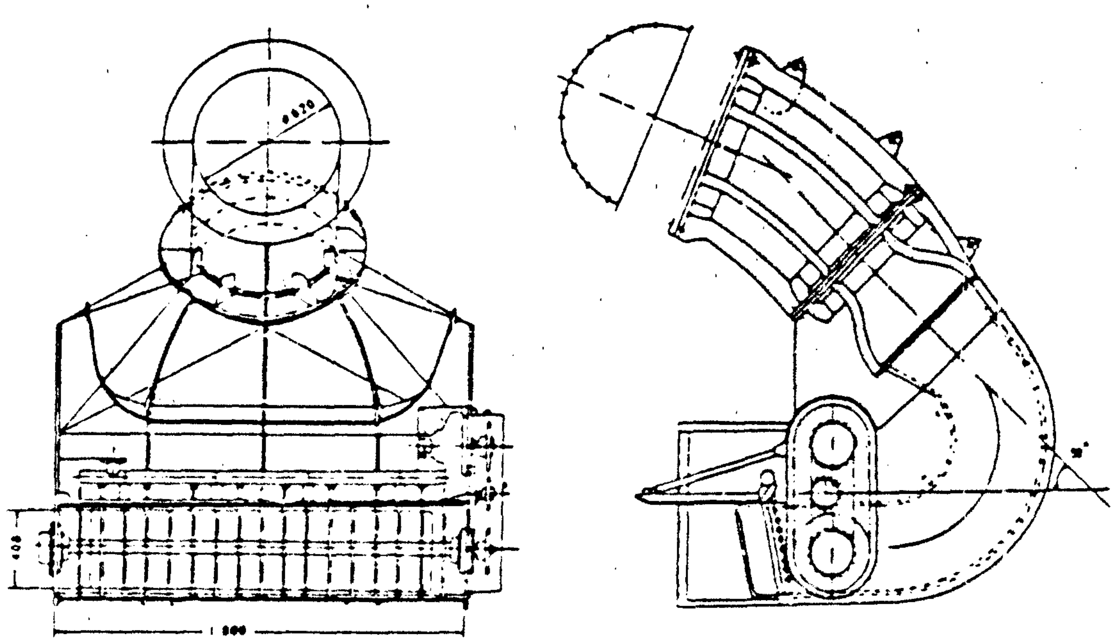


Figure 26. Drag head

Grain-size distribution of the soil, which was sampled from the inside of the hopper after dredging, is shown in Figure 27. The specific gravity of soil particles was 2.60.

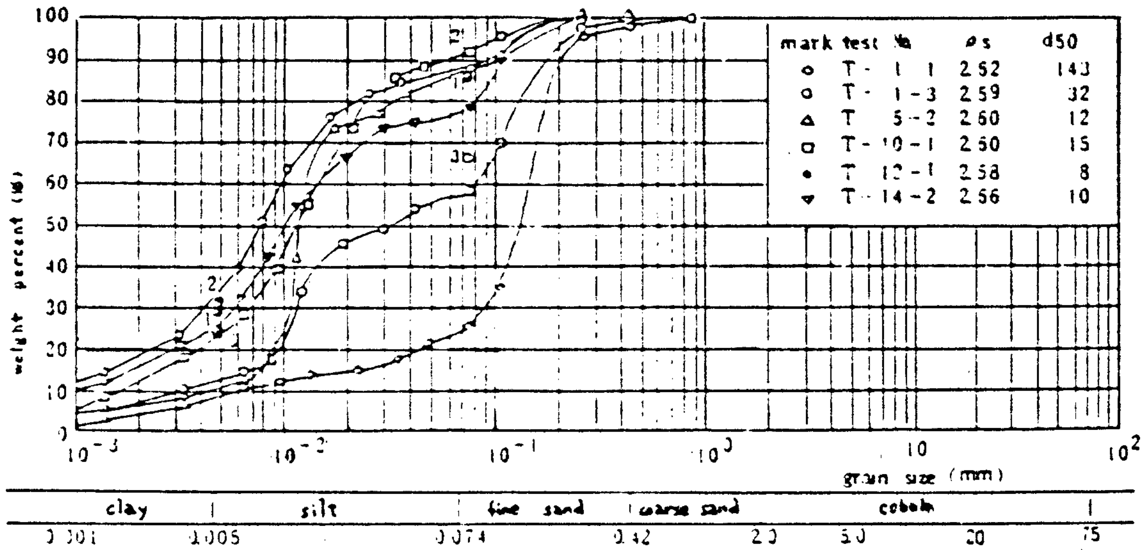


Figure 27. Grain-size distribution

Means of Test

Table 13 shows items of measurement. A detector for soft mud seabed surface was set in front of the drag head, a signal was amplified in the relay room near the drag arm trunnion, and output was simultaneously recorded by the data recorder in the bridge. Two water sampling pumps were fixed at the drag head, and one was at the middle of the drag arm. Measuring locations are shown in Figure 28.

Results and Analysis of Test

Results

In this test, the seabed was so uneven that it was very difficult to set up the depth of the drag head. We calculated the position of the drag head from the position and direction of the ship, and obtained the depth of the seabed by collating the position of the drag head with a sounding chart. Where the depth of the seabed, obtained as stated above, is S_{DR} and the depth of the sole of the drag head is S_{DH}, the relation to the thickness of dredging d_H is shown in Figure 29 and is written:

$$d_H = S_{DH} - S_{DR} \tag{10}$$

To obtain the characteristics of the dredging pump installed in "Seiryu Maru," we conducted a water supplying test and measured rate of water flow Q_0. The relation between Q_0 and the distance from the water surface to the pump D_{rp} is shown in Figure 30. Table 14 shows the results of this test.

Table 13. Items of measurement

No.*	Items	Location	Means	Note
1	Depth of the drag head	Drag head	Pressure transducer	
2	Suction pressure	Inlet of pump	Pressure transducer	
3	Discharge pressure	Outlet of pump	Pressure transducer	Continuously
4	Rolling of the vessel	Upper deck	Differential pressure transducer	
5	Hedoro layer	Inlet of head	Detector	
6	Rate of flow	Outlet of pump	Electromagnetic flow meter	Continuously
7	Density	Outlet of pump	Density meter	
8	Turbidity around head	Upon head	Submergible pump	
9	Turbidity around head	Upon head	Submergible pump	Several times per one run
10	Turbidity in background	Drag arm	Submergible pump	
11	Hedoro sampling	Open trough	Sampling valve	
12	Water level of hopper	Hopper	Float	Several times per one run
13	Hedoro sampling	Hopper	Ekman barge	
14	Draught	Bridge	Draught meter	
15	Depth of drag head	Bridge	Air barge	At intervals of 30 seconds
16	Velocity of the vessel	Bridge	Doppler log	
17	Position (Ra,Rb)	Bridge	Electric positioning equipment	At intervals of 10 seconds
18	Depth of dredging	Bridge	Echo sounder	Continuously
19	Rate of flow and density	Bridge	Electromagnetic flow meter and density meter	At intervals of 30 seconds
20	Suction, discharge press	Bridge	Bourdon pressure gauge	
21	Muddiness in test area		Turbidimeter	At intervals of 10 minutes
22	Water sampling	Craft	Water sampler	At intervals of 60 minutes

* Numbers corresponds to Figure 28.

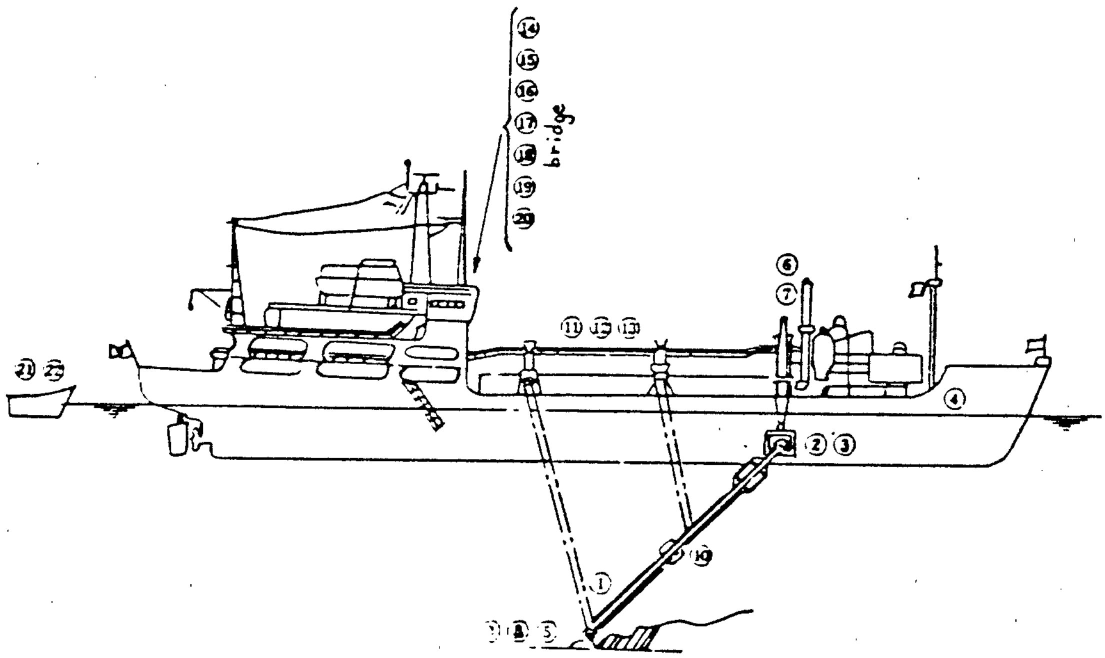


Figure 28. Locations of measurement

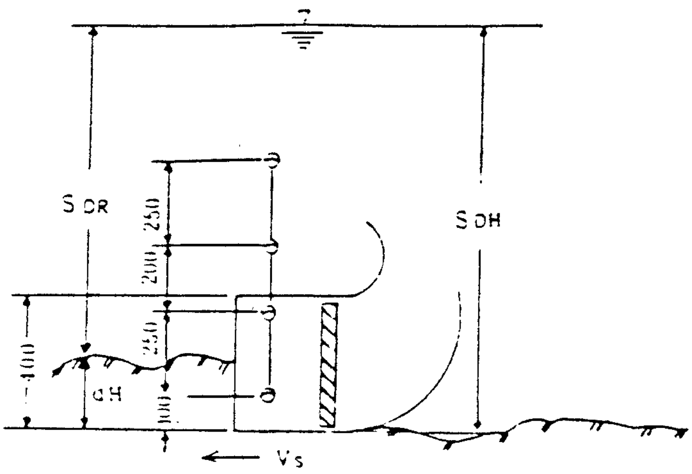


Figure 29. S_{DR}, S_{DH} and d_H

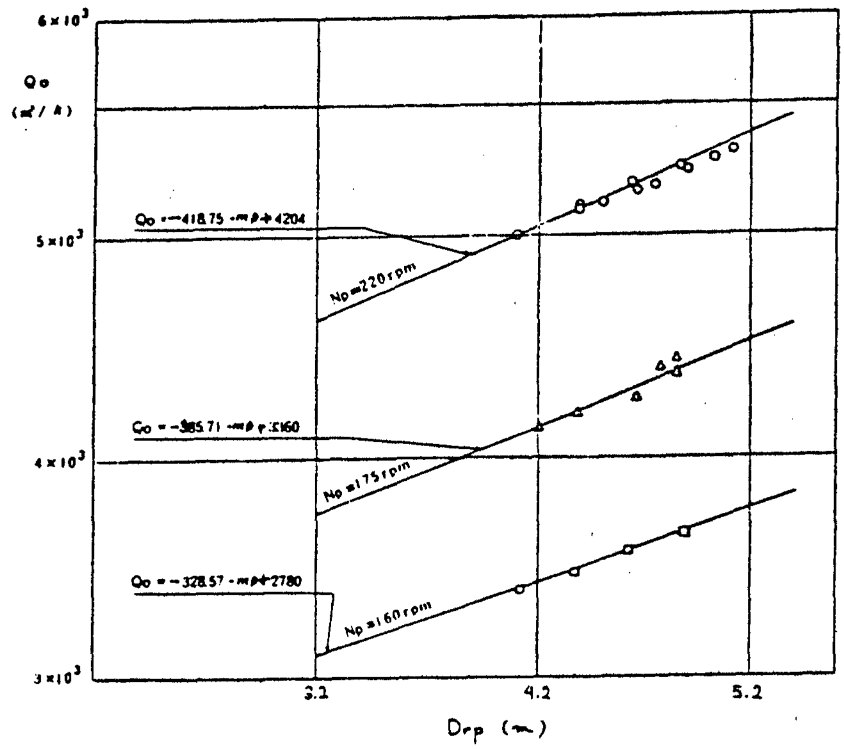


Figure 30. D_{r} and Q

Changes of Dredging Characteristics

Since the drag head could not follow the rolling sea bottom in this test, the thickness of dredging changed on a large scale. Therefore, we cannot discuss the average dredging characteristics. Instead, we can discuss changes in the dredging characteristics.

An example of the relation between the sea bottom and the depth of the drag head is shown in Figure 31. Generally, the drag head could maintain stability while following the gentle unevenness of the sea bottom; however, once the drag head got stuck in the mud of the sea bottom because of the roughness of the bottom, it took a long time to return to the stable condition. This was especially true for low water content. T2-3 in Figure 31 is an example of this phenomenon.

As for the relation between the control of the drag head and the bearing capacity of the bottom sediments (Hedoro), in spite of setting the pressure of the swell compensator for a maximum of 15 kg/cm^2 and with Hedoro being comparatively hard, the swell compensator operated only under the condition of the drag head getting into Hedoro of 60 - 70 cm. It is necessary to install a suitable stabilizer (one which is suited to the bearing capacity of Hedoro), and to control the depth of the drag head. When the water content is more than 250 - 300%, the stabilizer, which is suited to the bearing capacity of Hedoro, becomes an unrealistic size; in this case the drag head without a stabilizer can obtain better results.

Table 14. Results

Test No	Time min.	NP r.p.m.	NP r.p.m.	Sea Level m	SDH m	SDR m	Vs knot	Qm m³/H	VOLQ m³	Cv	γ	Volume of Dredging Soil m³	WTS ton	WTD ton	DORCT m³	DORAV m³	α
1 - 1	4.0	200	150	1.90	9.57	8.40	1.46	762	57	0.121	1.216	25	69	91	36	33	0.74
2	4.0	200	150	1.74	9.30	8.29	2.81	2981	224	0.060	1.120	47	250	291	87	61	0.78
3	5.0	200	150	1.68	9.24	8.29	3.03	3662	336	0.045	1.095	53	368	336	45	41	1.30
2 - 1	4.0	200	150	1.60	9.34	8.47	1.97	3452	259	0.061	1.121	56	290	317	63	44	1.25
2	4.0	200	150	1.73	9.27	8.27	2.39	2744	206	0.062	1.123	45	231	204	141	69	0.65
3	4.0	200	150	1.86	9.37	8.24	2.94	1728	130	0.126	1.224	58	159	203	203	129	0.45
3 - 1	4.0	200	300	2.26	9.77	8.24	2.18	3208	241	0.078	1.147	66	276	251	134	65	1.01
2	4.0	200	300	2.39	9.87	8.21	2.42	2956	225	0.074	1.142	59	257	240	198	147	0.40
3	5.0	200	300	2.46	9.99	8.26	2.93	3941	361	0.073	1.140	93	412	387	162	153	0.61
4 - 1	4.0	200	150	2.79	10.04	7.98	2.06	3207	241	0.089	1.166	76	280	253	122	66	1.15
2	4.0	200	150	2.84	10.30	8.19	2.57	2476	186	0.108	1.194	71	222	191	181	145	0.49
3	5.5	200	150	2.87	10.36	8.22	2.95	4094	409	0.051	1.105	74	453	448	216	175	0.42
5 - 1	4.0	200	300	1.56	8.94	8.11	2.40	3111	233	0.088	1.164	73	272	208	148	105	0.69
2	4.0	200	300	1.48	9.07	8.32	2.47	2923	219	0.117	1.210	91	265	267	130	119	0.76
6 - 1	6.0	200	0	1.44	8.87	8.16	2.08	3653	396	0.066	1.129	93	447	419	213	169	0.55
2	6.0	200	0	1.50	8.96	8.19	2.93	3634	394	0.064	1.126	89	443	419	172	112	0.80
7 - 1	6.0	200	0	2.34	9.92	8.31	2.50	4482	486	0.039	1.087	68	528	518	249	208	0.32
2	4.0	200	0	2.53	11.02	9.22	3.04	4253	319	0.025	1.064	28	339	247	100	85	0.33
8 - 1	5.0	200		2.38	10.10	8.45	1.83	4437	407	0.029	1.071	42	436	411	108	86	0.49
2	5.0	200		2.25	9.62	8.10	2.66	3519	323	0.069	1.134	79	366	378	94	66	1.20
9 - 1	5.0	200		1.60	9.34	8.47	2.52	4139	379	0.044	1.094	59	415	408	106	86	0.69
2	5.0	200		1.50	9.18	8.41	3.10	4021	369	0.075	1.143	97	421	421	60	58	1.67
10 - 1	6.0	160		1.23	8.95	8.45	2.02	2568	278	0.021	1.059	21	295	304	175	150	0.14
2	7.0	175		1.22	8.71	8.22	2.40	2707	338	0.072	1.138	86	385	384	236	107	0.80
11 - 1	5.0	200		2.73	10.43	8.43	1.84	4075	374	0.063	1.124	83	420	387	142	99	0.84
2	4.0	200		2.62	10.78	8.89	2.97	4182	314	0.052	1.107	58	347	346	101	79	0.72
12 - 1	5.0	200		1.81	9.65	8.57	3.45	3897	357	0.075	1.143	95	408	387	105	92	1.03
2	5.0	200		1.73	9.71	8.71	3.40	3904	358	0.071	1.137	90	407	391	112	105	0.86
13 - 1	5.0	200		1.18	8.80	8.35	2.01	4099	376	0.064	1.127	86	423	393	169	261	0.33
2	6.0	200		1.18	9.10	8.65	3.02	4199	455	0.082	1.154	132	525	543	236	319	0.41
14 - 1	5.0	200		1.50	9.01	8.24	1.96	3755	344	0.076	1.145	92	394	411	146	110	0.84
2	5.0	200		1.60	10.06	9.19	2.44	4728	433	0.015	1.049	23	454	446	97	86	0.27

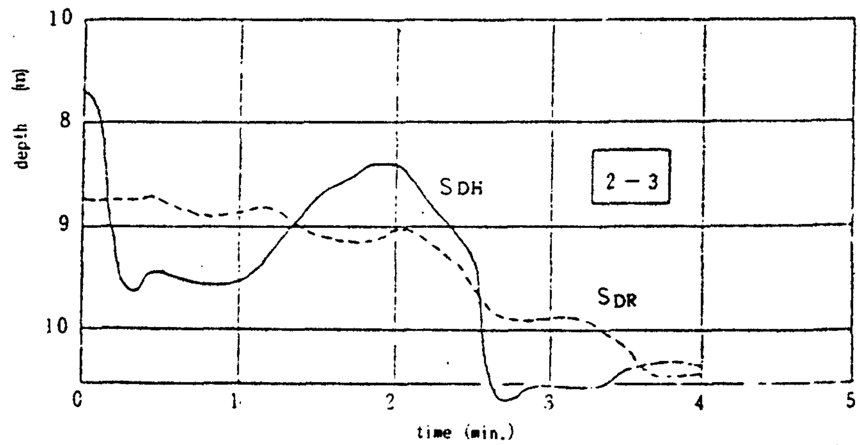


Figure 31. Sole of the drag head and sea bottom

The relations among thickness of dredging, density, and rate of flow are shown in Figure 32. Since they are arranged by the mean value, data are considerably scattered about, but the trend coincides with the results obtained before. To watch this as the relation to the dredging parameter, we obtain Figure 33. From this figure, the dredging boundary of this test is the point of $\Psi_o = 0.6 - 0.65$, which is at a lower level than that of the 1979 test.

In the California type drag head, the drag head touched the sea bottom widely and dredged soft mud which was diluted by surrounding water. The swell compensator operated effectively, but the density showed a downward trend.

Detector for Soft Mud Seabed Surface

It was confirmed that the detector for soft mud seabed surface operated effectively to grasp the relative relation between the drag head and the sea bottom on dredging. But the detector sometimes stopped the function by adherence of soft mud, so it is necessary to devise a method to avoid adherence of soft mud.

Turbidity Caused by Dredging

Since we had a lot of unentrained soil in this test, we saw a considerably high level of SS (suspended solids). Figure 34 shows the relation between the thickness of dredging and turbidity. We could not obtain a definite connection with the condition of dredging in this test.

FIELD DREDGING TEST (III) AT MIKAWA PORT

A field dredging test by "Seiryu Maru" was carried out at Mikawa Port, following the FY 1980 test. In order to improve operational performance, we

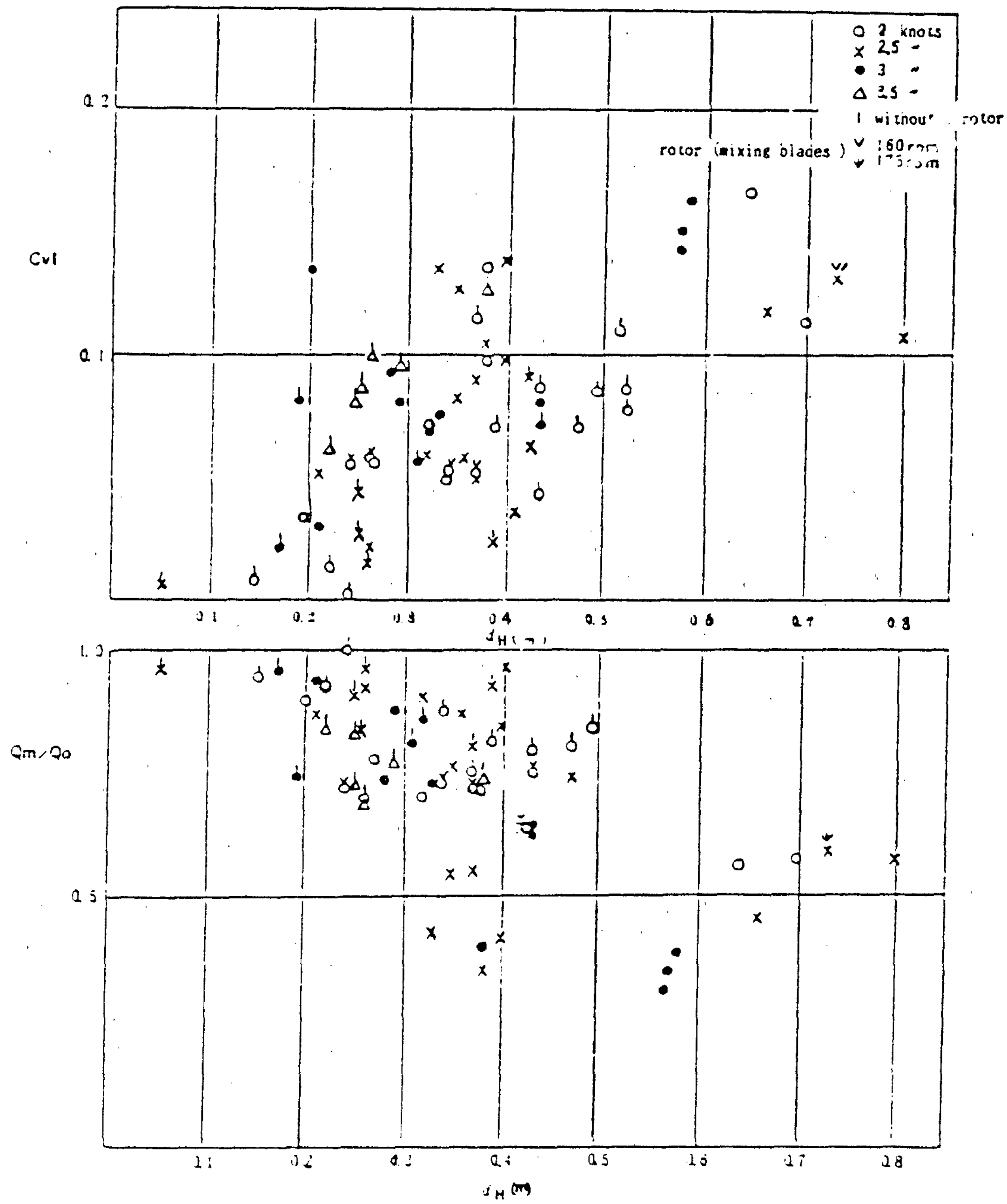


Figure 32. Thickness of dredging, density, and rate of flow

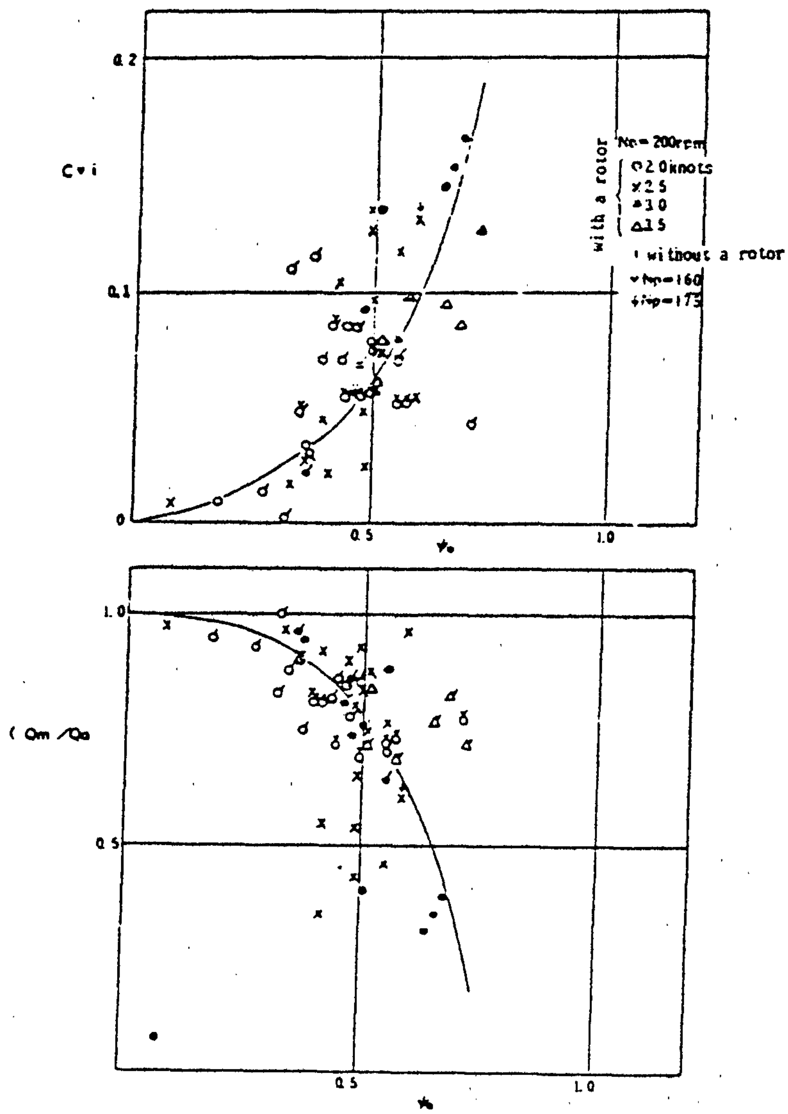


Figure 33. Ψ_o, rate of flow, and density

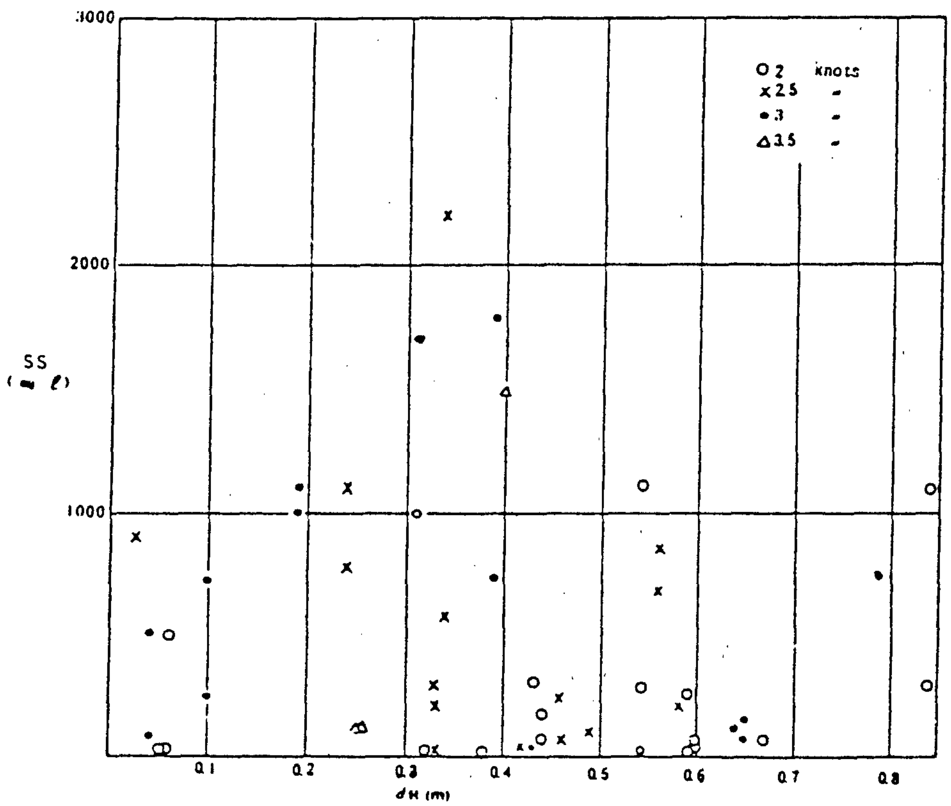


Figure 34. Thickness of dredging and turbidity

enlarged the stabilizer and reconstructed the drag head to control posture of the drag head by varying the angle of dredging.

Improvement of the operational performance of the Hedoro dredging system for practical use was the object of this test. The factors to be investigated in this test are as follows:

° Characteristics of dredging
° Automatic motion by means of the stabilizer and the swell compensator
° Relation between the posture of the drag head and the dredging performance
° Turbidity by dredging

Dredge

The dredge used in this test was the same trailing hopper suction dredge "Seiryu Maru." Main specifications are shown in Table 12.

Test Location

Location of this field test is shown in Figure 35.

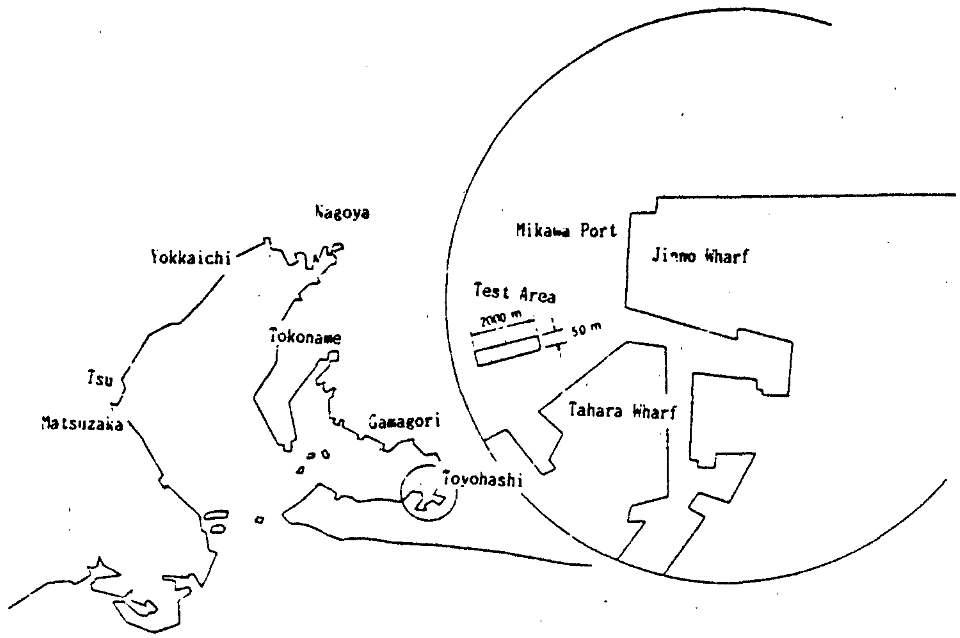


Figure 35. Location of the test

Drag Head

An outline of the drag head used in this test is shown in Figure 36. This drag head, which was manufactured by reconstructing the drag head used in FY 1970, had the same rectangular shape of breadth, B = 1 8 m, and height, H = 0.4 m.

Improvements of the drag head for this field test were as follows:

a. Installed a stabilizer of 7.0 m^2.

b. Made the bending part of the drag head movable in order to control the angle of dredging.

Bottom Soil Conditions

Locations and results of the soil test, which was carried out before the dredging test, are shown in Figure 37 and Table 15. Grain-size distribution of the soil, which was sampled from the inside of the hopper after dredging, is shown in Figure 38. Specific gravity of soil particles was 2.58.

Means of Test

Items of measurement are shown in Table 16, and locations of measurement are shown in Figure 39.

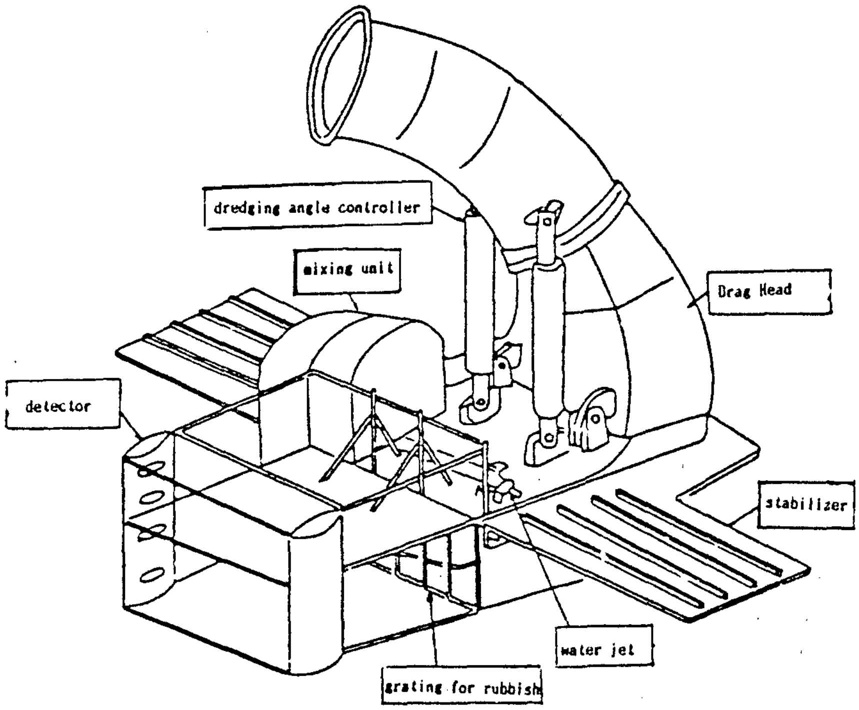


Figure 36. Drag head

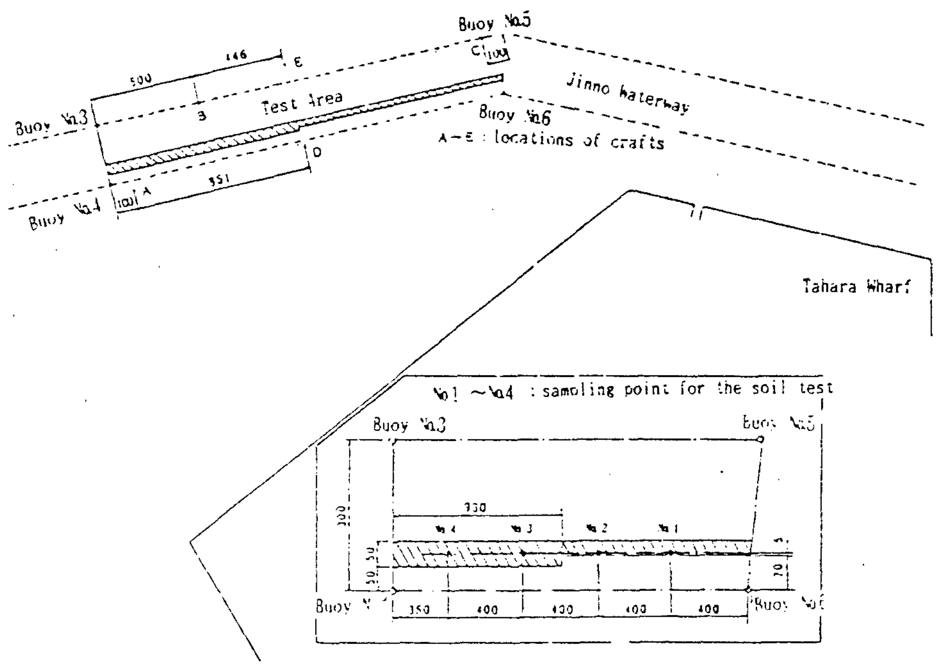


Figure 37. Locations of the soil test

Table 15. Results of the soil test

Sampling No.		Depth (m)	Specific Gravity	Water Content
	u	0.1 - 0.3	2.609	271.3
No. 1	m	0.4 - 0.6	2.649	176.4
	l	0.7 - 0.9	2.670	132.5
	u	0.1 - 0.3	2.626	231.3
No. 2	m	0.4 - 0.6	2.664	199.8
	l	0.7 - 0.9	2.674	185.9
	u	0.1 - 0.3	2.682	200.1
No. 3	m	0.4 - 0.6	2.644	194.3
	l	0.7 - 0.9	2.678	143.7
	u	0.1 - 0.3	2.640	187.4
No. 4	m	0.4 - 0.6	2.664	154.7
	l	0.7 - 0.9	2.663	127.3

u:upper layer
m:middle layer
l:lower layer

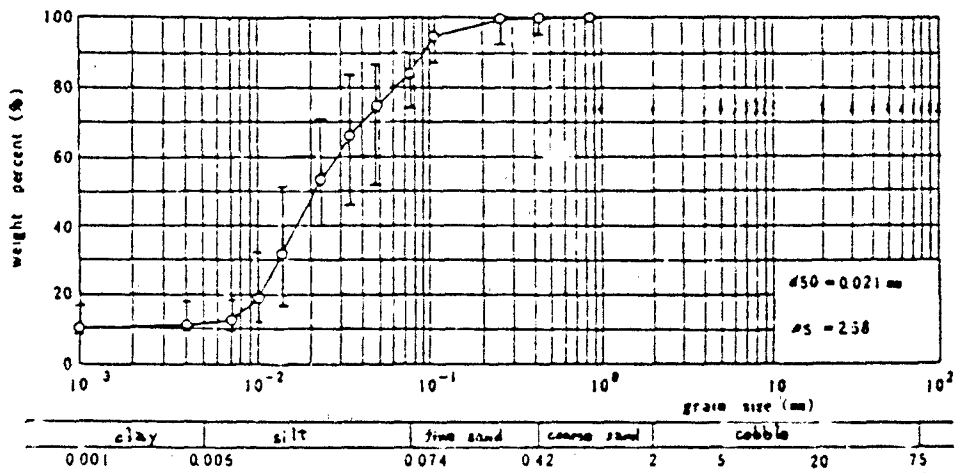


Figure 38. Grain-size distribution

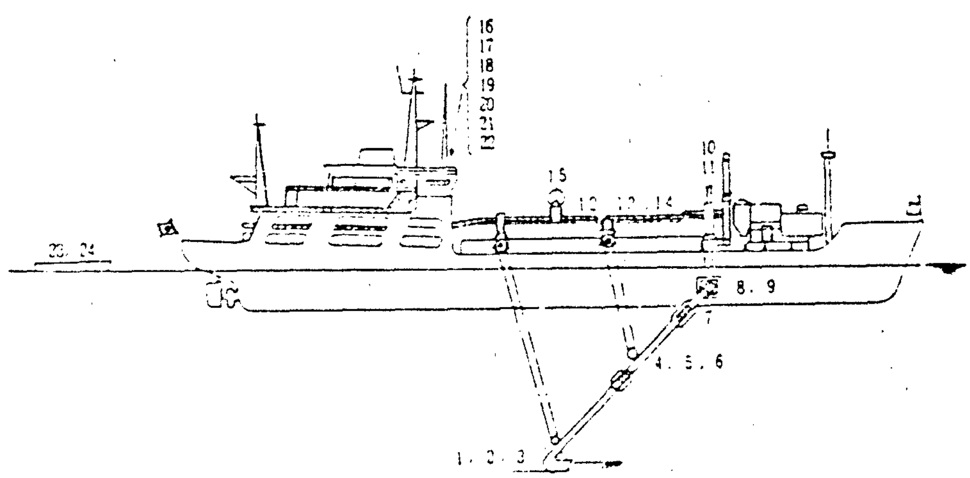


Figure 39. Locations of measurement

Table 16. Items of measurement

No.*	Items	Location	Means	Note
1	Depth of the drag head	Drag head	Pressure transducer	Continuously
2	Hedoro layer		Detector	
3	Turbidity around drag head		Submergible pump	Several times per one run
4	Depth of the new bottom		Echo sounder	Continuously
5	Depth of the middle of the drag arm		Pressure transducer	Several times per one run
6	Turbidity in the background		Submergible pump	Continuously
7	Depth of the end of the drag arm		Pressure transducer	
8	Suction pressure of pump	Inlet of pump		
9	Discharge pressure of pump	Outlet of pump		
10	Rate of flow		Electromagnetic flow meter	
11	Density		Density meter	
12	Hedoro sampling	Open trough	Sampling valve	Several times per one run
13	Water level of the hopper	Hopper	Float	
14	Hedoro sampling		Ekman barge	
15	Displacement of swell compensator	Swell compensator	Potentiometer	Continuously
16	Draught	Bridge	Draught meter	At intervals of 30 seconds
17	Depth of the drag head		Air barge	
18	Velocity of the ship		Doppler log	
19	Position (Ra,Rb)		Electric positioning equip.	
20	Thickness of dredging		Echo sounder	Continuously
21	Rate of flow density		Electromagnetic flow meter & density meter	At intervals of 10 seconds
22	Suction pressure, etc.		Bourdon pressure gauge	
23	Turbidity in the test area	Craft	Turbidimeter	10 minutes
24	Water sampling in the test area		Water sampler	60 minutes

* Numbers correspond to Figure 39.

Results and Analysis of Test

Marine and Meteorological Conditions

Meteorological conditions (Table 17), were generally good; marine conditions were also good.

Table 17. Meteorological conditions

		Wind					
Date	Time	Direction	Speed (m/s)	Weather	Temperature (C)	Humidity (%)	Atmospheric Press, (mb)
8/24	12:00	E	3	Clear	26	58	1002
8/25	12:00	E	5	Cloudy	26	75	1010
8/26	12:00	SW	4	Cloudy	26	90	1005
8/29	12:00	SE	7	Cloudy	28	74	1004
8/28	12:00	W	3	Cloudy	24	82	1009

Results

The result of the water supplying test is shown in Figure 40. Table 18 lists all the results of this field dredging test. Since T-15 in Table 18 is the result of the California type drag head and the bases are different, analysis of the relation between T-15 and other cases is meaningless; therefore, we did not examine these results. Water content of the soil, which was used in the analysis of the test data, is obtained from Table 15.

$$W_n = 220\%$$

This is the mean value of the water content of the soil at a depth of 0.2 m.

Dredging Characteristics

Dredging characteristics are determined by taking that of the drag head without a stabilizer for the basis. A downward trend of the rate of flow becomes Figure 41. This is expressed by the following empirical formula:

$$Q_m/Q_o = 1 - 4.59\ C_v^{1.3} \qquad (11)$$

The broken line in Figure 41 expresses the data of the usual fine sand dredging test. The rate of flow of this test drops well as compared with

Table 18. Results

Date 1981	Test No.		dredging time m.	dredging time s.	depth of sea bottom (m)	sea level (m)	rate of flow (m^3/H)	density Cv	thickness of dredging (m)	dredging volume (m^3)	effective dredging vol. (m^3)	volume of dredging soil (m^3)	dredging parameter Ψ_*	angle of dredging α	velocity (kt)
8/24	1	1	7	00	13.3	1.58	3.996	0.101	0.59	501	339	308	0.533	3.5	2.18
		2	5	20	13.0	1.51	4.855	0.063	0.17		155	178	0.311	2.5	3.07
8/25	2	1	6	00	12.0	0.67	4.213	0.085	0.50	432	346	234	0.635	2.1	2.59
		2	5	40	11.9	0.71	5.405	0.026	0.18		199	87	0.377	1.5	3.50
	3	1	6	00	12.2	1.07	5.002	0.055	0.37		254	173	0.465	0.5	2.03
		2	4	19	13.0	1.15	5.203	0.029	0.08		58	71	0.144	0.4	3.01
	4		11	37	12.8	1.54	4.686	0.060	0.35		604	356	0.565	0.3	2.67
	5	1	6	00	13.2	1.91	4.504	0.059	0.38		265	174	0.483	0.4	2.09
		2	3	15	13.7	1.91	5.216	0.015	0.14		76	28	0.252	1.2	3.02
8/26	6	1	6	00	11.8	0.12	4.718	0.081	0.43	375	348	250	0.611	0.6	2.61
		2	5	30	12.3	0.42	5.040	0.041	0.30		318	124	0.624	0.4	3.47
	7		11	45	11.6	0.61	4.840	0.063	0.36		612	300	0.568	2.9	2.60
	8	1	6	00	12.6	1.17	4.929	0.010	0.20		207	129	0.381	1.0	3.10
		2	5	23	13.6	1.25	4.833	0.061	0.32		293	173	0.588	2.9	3.06
	9	1	6	00	13.1	1.80	4.723	0.059	0.42		315	182	0.581	1.0	2.36
		2	5	30	13.7	1.86	4.901	0.051	0.24		225	150	0.442	2.6	3.07
8/27	10	1	6	00	11.5	0.48	4.760	0.065	0.51		272	202	0.503	1.2	2.01
		2	5	25	11.8	0.42	5.190	0.049	0.28		254	150	0.507	0.0	3.01
	11	1	6	00	11.7	0.17	5.107	0.014	0.36		246	147	0.454	1.6	2.05
		2	5	00	11.8	0.54	5.128	0.046	0.31		260	128	0.563	0.6	3.02
	12	1	6	00	12.0	1.05	5.076	0.040	0.30		264	133	0.488	1.2	2.64
		2	4	38	13.1	1.27	5.443	0.002	0.09		84	6	0.196	1.3	3.62
	13	1	6	00	12.8	1.80	4.869	0.051	0.37		441	162	0.813	0.6	3.57
		2	5	16	13.5	1.86	5.265	0.026	0.27		238	79	0.489	1.4	3.01
	14	1	6	00	13.3	2.45	4.258	0.085	0.74	521	281	236	0.520	2.5	2.11
		2	6	00	13.3	2.25	4.885	0.062	0.58	612	611	198	0.760	0.2	3.16
8/28	15	1	5	00	12.2	0.63	4.414	0.093	0.531	320		224			1.96
		2	8	00	12.0	0.55	3.797	0.144	0.631	906		476			2.71

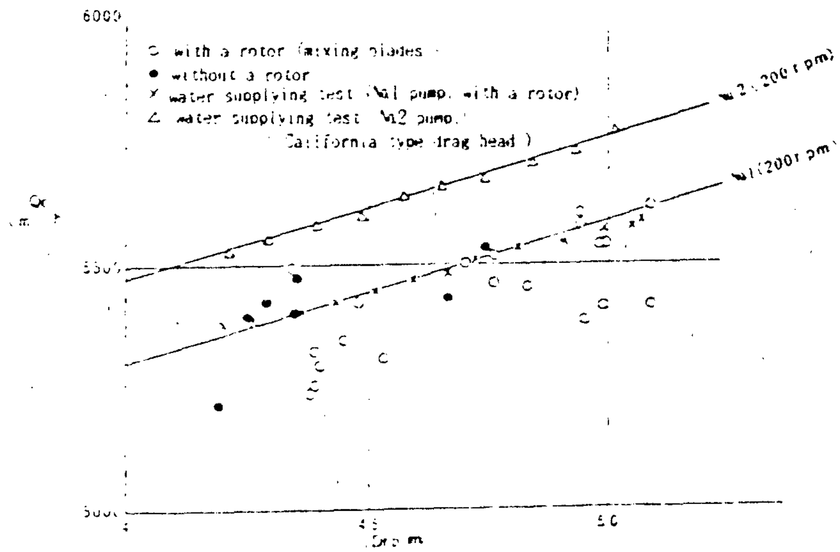


Figure 40. Water supplying test

that of the fine sand dredging test. The following equation expresses the quantity of solids dredged per unit time:

$$G_s/Q_o = 6.534\ C_v\ \ 1 - 4.59\ C_v^{1.3} \tag{12}$$

To differentiate Equation 12, the quantity of solids dredged per unit time becomes maximum at the density of 16.3%. But the natural density of the soil (Hedoro) in the seabed C_B was only 15.3%, so the density did not increase to the peak value, and the pump operated only at 60% of capacity.

The relation between the suction density and Ψ_o is shown in Figure 42. This figure shows that the density is low when d_H is under 0.4 m and increases steadily when d_H is over 0.4 m. An illustration which expresses the model of this phenomenon is shown in Figure 43.

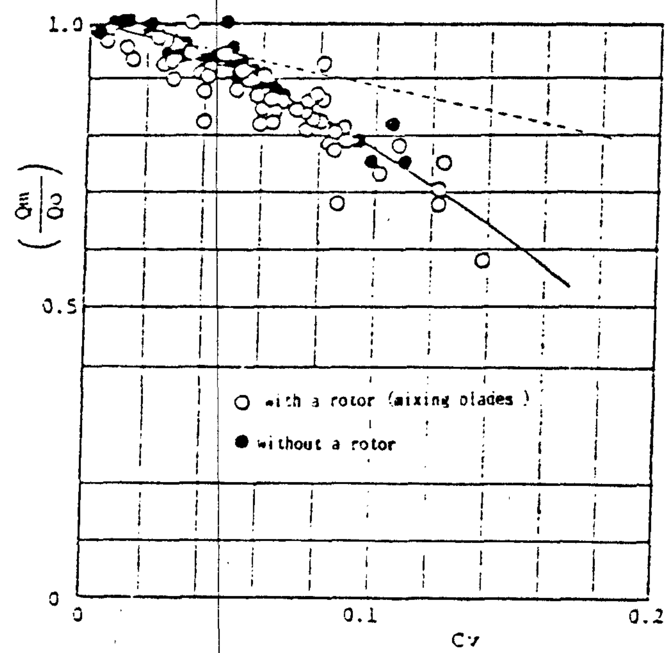


Figure 41. Density & rate of flow

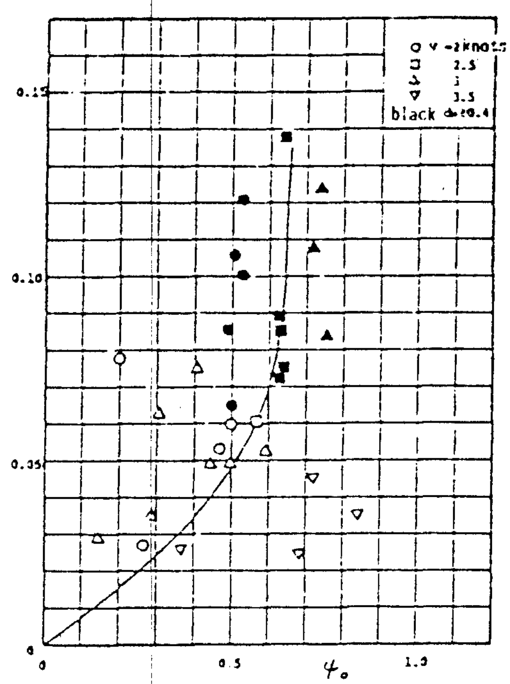


Figure 42. Density and ψ_o

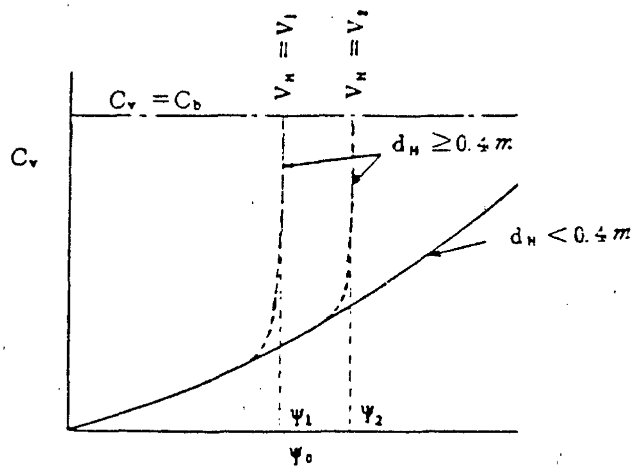


Figure 43. Model of the basic dredging characteristic

Installation of the stabilizer influenced the characteristics of dredging when the velocity of the ship V_s was over 3 knots. When the drag head was buried, the stabilizer clogged the flow route of Hedoro, but when the drag head was not buried, water easily diluted Hedoro.

The ratio of dredged Hedoro RR is shown in Figure 44 and is expressed as follows:

$$RR = (C_a \cdot Q_m)/(B \cdot d_H \cdot V_H) = \varepsilon \tag{13}$$

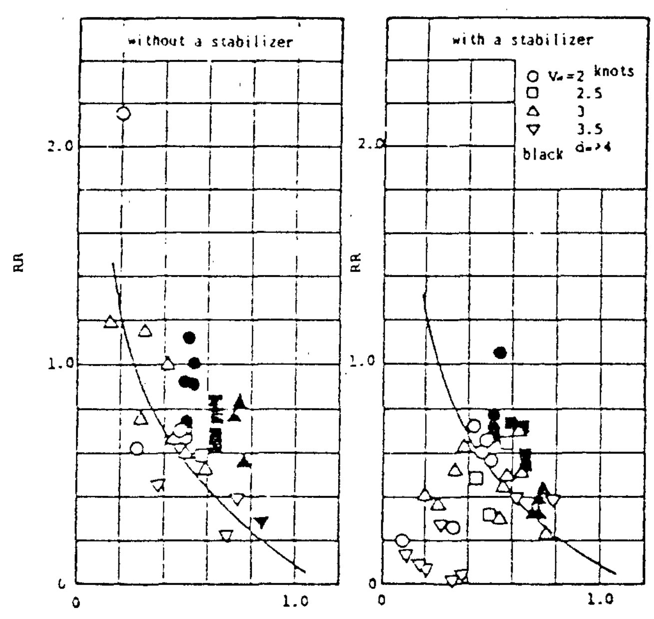


Figure 44. ψ_o and RR

For a drag head without a stabilizer, RR is 0.6 - 1.0 and the difference by the velocity of the ship is small. For a drag head with a stabilizer, the trend of RR is similar to that of the head without a stabilizer when the velocity of the ship is 2 - 2.5 knots. But when it is over 3 knots, influence of the stabilizer is exerted and the dredging efficiency drops.

Effect of Stabilizer

The (horizontal) stabilizer influences the characteristics of dredging, and many planning problems remain; however, the stabilizer complements the function of the swell compensator.

Figure 45 shows the comparison of the thickness of dredging between the case of using the drag head with a stabilizer and that of using the drag head without a stabilizer. We can find that the thickness of dredging shows a stable condition near 0.4 m when using the drag head with a stabilizer. An effect of the stabilizer is influenced by the angle between the drag head and the seabed (α). The reason is that a little change to the angle α changes the lift operating upon the stabilizer, and the swell compensator can operate effectively only when the lift operates upon the stabilizer. (This is because the lift makes up for a deficiency of the load bearing capacity of Hedoro, bottom sediments, and makes the good condition for the operation of the swell compensator.)

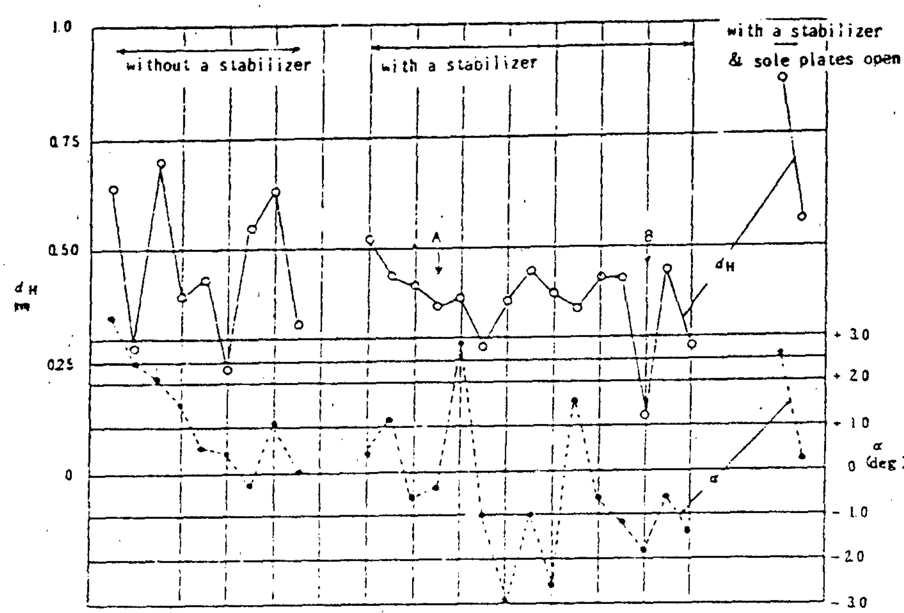


Figure 45. Thickness of dredging

Detector for Soft Mud Seabed Surface

Four pairs of sensors were installed, but soft mud (Hedoro) adhered to the sensors located above the inlet of the drag head; therefore, recovery of the function of the sensor was sometimes delayed. The two pairs of sensors located under the upper plate of the inlet of the drag head operated without problem. Patterns of the receiving level of these two pairs of sensors are shown in Figure 46. Judging from this figure, these sensors are considerably effective when the velocity of the ship is near 2 knots; but when velocity is over 3 knots, these sensors often indicate incorrect patterns.

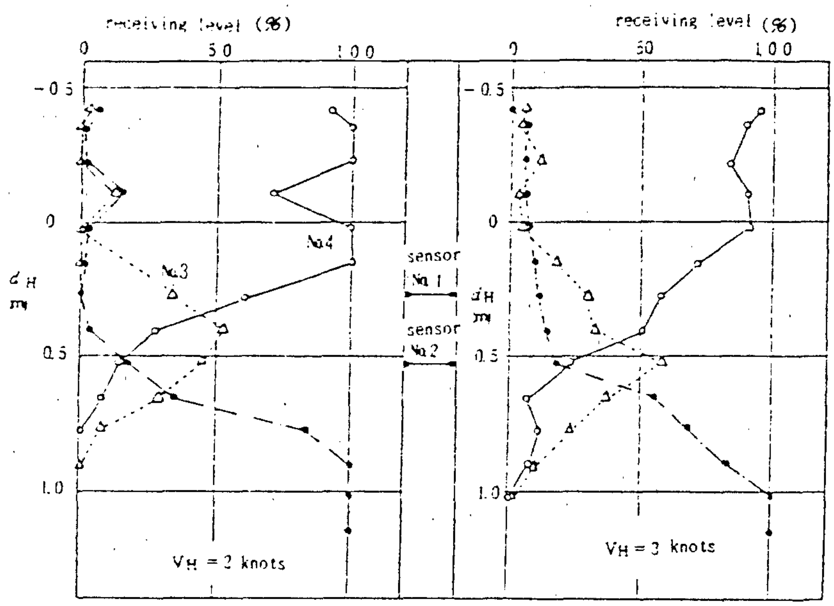


Figure 46. Patterns of the receiving level

Turbidity

Turbidity appeared deeply and widely near the drag head, but we could not link turbidity with the dredging conditions. Two kinds of turbidity appeared near the drag head: one about 10 times as deep as turbidity of the background and always in the stable dredging condition; and the other very deep with turbidity of about 5000 mg/ℓ. The latter appeared due to soft mud, which accumulated on the drag head, being washed by water when the drag head rose up to the sea bottom after being buried. But this sort of turbidity appeared only infrequently and hardly influenced the background.

Measures for Improvement

Effective Position of Horizontal Stabilizer

It is possible to follow the sea bottom by means of the horizontal stabilizer and the swell compensator where a bearing capacity of soft mud (Hedoro) is expected. The position of the stabilizer is important. It is necessary that the stabilizer enable an easy lift and not obstruct the inflow of Hedoro. The stabilizer should be installed a short distance behind the inlet (front) of the drag head.

Detector for Soft Mud Seabed Surface

Since two pairs of sensors installed under the upper plate of the inlet of the drag head operated acceptably well, it is reasonable to control the drag head by a system which uses the signals of these sensors. But the frontal projected area of these sensors needs to be reduced so as not to obstruct the inflow of Hedoro.

CONCLUSIONS

Seven years have passed since we started this development. During these seven years, we carried out four experiments with models and three field dredging tests. A summary of these field tests is shown in Table 19. Circumstances of the test areas of these field tests are different from each other, and the dredges "Tokushun Maru No. 1" and "Seiryu Maru" were used. Therefore, we cannot discuss results of these tests from the same point of view. We carried out these tests with the front open type drag head and the trailing hopper suction dredge for removal of a large volume of Hedoro in a large area and to protect cruising ships.

Through these tests, we developed the technology of the front open type drag head. In order to make this technology of practical use, a few operational problems remain: improvement of the handling performance, and the need for a means of positioning the ship and the drag head. When these problems are solved, the drag head will automatically follow the sea bottom, and dredging pumps and engines of the dredge will be automatically controlled by microcomputer which processes the dredging conditions continuously. A study of some of these problems has already been conducted, but more data are needed.

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Table 19. Summary of the field dredging tests

Year	1979	1980	1981
Location	Chiba Port	Nagoya Port	Mikawa Port
Soil	Silty clay	Clayey silt	Silty clay
grain size (D_{50})	0.006-0.012mm	0.008-0.06mm	0.002-0.024mm
water content	180-340%	50-130%	130-270%
Drag head			
shape	Front open type B 2.3m * H 0.5m	Front open type B 1.8m * H 0.4m	Front open type B 1.8m * H 0.4m
mixing blades	150, 300 rpm	150 rpm	150 rpm
stabilizer	2.55 m^2	1.62 m^2	6.96 m^2
detector	4 pairs	4 pairs	4 pairs
Density			
true vol. density	1.5-15%	0-17%	2-14%
apparent density	10-98%	0-60%	16-91%
Dredging parameter	0.1 - 0.85	0.10 - 0.70	0.15 - 0.85
Turbidity	Around the drag head usually under 10 mg/ℓ	Around the drag head usually under 30 mg/ℓ	Around the drag head usually under 30 mg/ℓ
Note	Characteristics of dredging were clarified	Characteristics of dredging by "Seiryu Maru" were also clarified	How to control the drag head by means of the stabilizer and the swell compensator was clarified
Dredge	"Tokushun Maru No. 1"	"Seiryu Maru"	"Seiryu Maru"

NOTATION

A_H : Area of the inlet (front) of the drag head (= B·H) (m^2)

Ap : Cross-sectional area of the pipe of the drag arm (m^2)

A_q : Pressure unit expressed by the height of aqua (water)

B : Breadth of the inlet (front) of the drag head (m)

C_a : Apparent density

C_B : True volume density of the bottom sediments

C_V : Average true volume density

C_{Vi}: Volume density in the inlet (front) of the drag head

C_{Vm}: Volume density in the drag arm

D : Diameter of the mixing blades (m)

d_H : Thickness of dredging (m)

D_{rp}: Distance from the water surface to the dredging pump (m)

G_s : Quantity of solids dredged per unit time (= $C_V \cdot Q_m$) (m^3/hr)

H : Height of the inlet (front) of the drag head

h_R : Added resistance (m Aq)

h_V : Suction pressure (m Aq)

I_P : Plasticity index (%)

m_p : Distance from the water surface to the dredging pump (m)

Q_o : Water supplying quantity of the dredging pump (m^3/hr)

Q_{IN}: Quantity of solids forcibly supplied into the drag head (= $B \cdot d_H \cdot V_S$) (m^3/hr)

Q_m : Mean rate of flow (m^3/hr)

S_{DR}: Depth of the seabed at the drag head (m)

S_{DH}: Depth of the sole of the drag head (m)

V_H : Velocity of the drag head (m/sec)

V_m : Velocity of solids in the drag arm (= Q_m/Ap) (m/s)

V_p : Velocity of water in the drag arm ($= Q_o/Ap$) (m/s)

V_s : Velocity of the dredge (m/s or knots)

W_L : Liquid limit (%)

W_n : Natural water content (%)

W_p : Plastic limit (%)

W_o : Water content of pseudo Hedoro (%)

γ_b : Specific gravity of bottom materials

γ_m : Mean specific gravity of slurry

γ_s : Specific gravity of soil particles

γ_v : Specific gravity of seawater

τ_o : Shearing strength (kg/cm^2)

Ψ_o : Dredging parameter ($= Q_{IN}/Q_o$)

Ψ_{oc} : Dredging parameter at blockage boundary

ε : Ratio of dredged Hedoro ($= (C_v\ Q_m)/(Q_{IN}\ C_B)$=RR)

α : Angle between the drag head and the seabed

OVERVIEW OF CORPS RESEARCH PROGRAM ON DREDGING CONTAMINATED SEDIMENTS

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ABSTRACT

The problems of dredging contaminated sediments with existing conventional equipment and techniques are discussed. These problems exist because the dredging practices in the United States have evolved to achieve the greatest possible economic returns through maximizing production. As a result, conventional dredges are not specifically designed or intended for use in dredging highly contaminated sediments. However, many feel that dredges are the logical, and perhaps only, means of removing contaminated sediments that have been found in the Nation's harbors and waterways. It is also felt that some modifications to equipment and dredging techniques could result in their use in dredging highly contaminated sediments with minimal adverse impact on the environment.

This paper outlines active research at the Waterways Experiment Station on equipment and techniques for dredging contaminated sediments. The question of dredging in contaminated sediments is being addressed in three ways: the assembly and evaluation of available domestic and foreign information concerning sediment resuspension and contaminant release, the development of appropriate laboratory tests to predict contaminant release from resuspended sediments, and the use of field studies to monitor performance and compare dredges operating under various conditions. Plans are discussed for evaluating existing dredging equipment to determine best techniques for dredging sediments that are highly contaminated with toxic substances. Initial field studies have already been completed on evaluating sediment resuspension at the point of dredging for cutterhead, dustpan, and clamshell dredges. The results of these preliminary studies are discussed.

INTRODUCTION

Background

The Waterways Experiment Station (WES) has initiated studies to determine the relative effectiveness of various methods of dredging contaminated sediments. These studies are being conducted as part of the Improvement of Operation and Maintenance Techniques (IOMT) Research Program. The specific

environmental concerns addressed include resuspension of contaminated sediments and the possibility of contaminant release during the dredging operation. Although specific dredging operations involving contaminated sediments have been monitored by various Corps offices and governmental regulatory agencies, data are not available on a national basis to allow the prediction of the impact of the operation of a specific dredge in a given situation.

Conventional dredges are not specifically designed or intended for use in dredging highly contaminated material. However, dredges are the logical, and perhaps only, means of removing contaminated sediments that may be found in the Nation's waterways. Some modification to equipment and/or dredging techniques could result in their use for that purpose with minimal adverse impact on the environment. In some instances special dredges may be needed for cleanup activities.

While WES extensively studied the effects of aquatic disposal of dredged material during the Dredged Material Research Program (DMRP), little research was done concerning the resuspension of the bottom sediments that occurs due to the actual dredging operation. The IOMT field studies are designed to determine the extent and character of bottom sediment plumes resuspended during dredging. These studies will provide information on which to base an assessment of the relative performance of different dredges and dredging techniques with regard to their sediment resuspension characteristics.

The introductory work in this area was conducted by Barnard (1978) during the DMRP. He performed a review of the limited literature available on dredge-induced turbidity. He found that most conventional dredges create a low concentration plume of silt and clay-sized particles (diameter less than 0.03 mm) or small flocs (masses of agglomerated particles) that settle independently through the water column at very slow rates. Although the solids concentrations in the water column in the vicinity of the dredging operation usually do not exceed several hundred milligrams per liter (mg/ℓ), the particles/flocs continue to settle until the solids concentrations near the bottom can exceed 10 grams per liter (g/ℓ). This level of concentration (0–10 g/ℓ) of suspended solids he referred to as turbidity. Concentrations higher than this level take on the properties of the naturally occurring "fluid mud" layers which often form over more dense bottom sediments.

Research Objectives

The objectives of this research are to develop procedures for predicting potential resuspension and release of contaminants using various types of dredging equipment and techniques and to improve and/or develop new equipment and techniques for dredging highly contaminated sediments.

Research Approach

The environmental impact associated with different types of dredging equipment and techniques will be determined. Available domestic and foreign information on sediment resuspension and contaminant release will be assembled and evaluated. The investigation will include an evaluation of the resuspension of solids and potentially toxic constituents in the immediate vicinity of the dredge. Because the environmental impact associated with each type of

dredge and dredging technique is directly related to the dynamics of the dredging operation, an in situ sampling system will be implemented. Sampling will be performed in the immediate vicinity of the dredge, in background waters, and in ship/barge-generated plumes. Data will be collected at a minimum around operating cutterheads, dragheads, and clamshells. Any other innovative systems that may be available will be evaluated. The operation of each type of dredge will be varied, to the degree practical, to determine the relationship between technique, production, and sediment resuspension. This information will be the basis for comparing the degree of sediment resuspension caused by the dredging equipment and techniques.

The end product of the studies will be a method to predict on a site-specific basis the degree and extent of resuspension of sediments and contaminant release from dredging operations. The predictive methodology will allow for sound decisions to be made on selection of the type of equipment required for dredging contaminated sediments.

The first phase of the study will be to collect and analyze data available from various Corps offices and other agencies in order to establish a general data base on the performance of conventional dredges. The performance of a dredge is based on numerous factors and development of a methodology for predicting performance must consider these factors. Performance data from field tests where parameters are held constant will be used later to develop a predictive capability.

Data have been collected by several Corps of Engineers Districts including the San Francisco, Norfolk, Mobile, New York, and others. This information will be gathered, analyzed, and possible comparisons drawn between similar dredging equipment operating under differing conditions. For each instance, information concerning dredge types, operating characteristics, sediment types, hydraulic conditions, measurement of turbidity due to resuspension, and analysis of data concerning contaminant release will be compiled. If possible, comparisons of different dredges and dredging techniques under similar conditions will be made. The objective of compiling these data is to aid in the future development of relative rating factors for potential resuspension of contaminants for each of several dredging types and dredging conditions.

The Norfolk District conducted a major field evaluation of two types of equipment to be used to dredge the Federal channel in the Kepone-contaminated James River. This operation provided an opportunity to compare the performance of a conventional cutterhead dredge and that of a dredge equipped with a specifically designed dustpan head. Environmental parameters were closely monitored at the dredging and disposal sites. These data provided extensive information for the comparison of conventional and nonconventional equipment.

Preliminary evaluations of specialized dredging equipment were conducted under the DMRP. These existing data concern watertight, clamshell dredge buckets, suspended solids generated in the vicinity of conventional cutterhead dredges as a function of production rate, and use of the Oozer pump dredge and Clean Up Dredging System. Additional information on such nonconventional dredges will be collected. Data on United States and foreign dredges specifically designed to clean up highly contaminated sediments will be obtained.

A predictive methodology will be developed relying on a factor rating system for evaluating the performance of specific types of dredging equipment and corresponding dredging techniques. This factor rating system will be used to evaluate the potential for resuspension of contamination in the immediate vicinity of the dredge head. Evaluations of laboratory testing techniques for predicting contaminant release for specific sediments and evaluation of dispersion using existing models or methods for various hydraulic dispersion conditions will also be completed. All three elements (the factor rating system for equipment and dredging techniques, the laboratory test for prediction of contaminant release, and the evaluation of dispersion for various hydraulic conditions) will be integrated into a matrix approach to evaluate overall potential for contaminant release due to the dredging operation.

The major impetus for these field studies however is not concern with the resuspension of sediment for its own sake, but the fact that the sediments of many of the Nation's waterways have become repositories for contaminating materials. This problem has arisen due to the affinity of these contaminates, particularly chlorinated hydrocarbon pesticides and PCB's, for the clay-sized particles and natural organic solids found in most river sediments. When these sediments are disturbed, such as during dredging operations, contaminants may be transferred back to the water column, either through resuspension of the sediment solids, dispersal of interstitial water, or desorption from the resuspended solids. Investigation by Fulk, Gruber, and Wallschleger (1975) indicated that for sediment-water concentrations of less than 100 g/ℓ the amount of pesticides and PCB material that dissolved or desorbed into the water column from the resuspended sediment is negligible. They determined that basically all pesticide materials were transferred to the water column by means of resuspension of solids.

LABORATORY INVESTIGATIONS

An evaluation will be made of the applicability of elutriate testing as an indicator of potential contaminant release due to resuspension of sediments during dredging operations. The existing elutriate test procedures reflect conditions due to open-water disposal operations. Resuspension during dredging operations involves shorter agitation times than that resulting from disposal. Modifications to the standard testing procedures will be proposed to allow better applicability of elutriate testing to the case of resuspension at the point of dredging.

FIELD STUDY METHODOLOGY

Method of Suspended Sediment Measurement

Both Barnard (1978) and Stern and Stickle (1978) point out the problems of finding a commonly accepted method of suspended sediment measurement. Both indicate the majority of previous efforts were concerned with the measurement of turbidity, which is an optical property of water. Turbidity measures the reduction of light passage through water due to suspended particles. Turbidity, however, cannot be correlated with weight concentration of suspended matter because the optically important factors of size, shape, and refractive index of

the particulate materials bear little relationship to the concentration and specific gravity of the suspended matter. This fundamental problem is exacerbated by the fact that there are two major optical means of measuring suspended sediment level, transmissometery (percent of light passing directly through) and nephelometery (amount of light scattered). Therefore, results may be reported in terms of several different types of turbidity units.

Based on these findings, the preferred method of measurement for the IOMT field studies would be gravimetric rather than optical. This method allows a more accurate comparison of different dredging operations involving different sediment types, gives a truer indication of what is actually occurring during a dredging operation, and permits more precise estimates of the potential settleable solids. Stern and Stickle (1978) particularly mention the lack of the latter as a major obstacle in determining the effect of dredging on aquatic organisms. The gravimetric method used throughout these field studies is that prescribed by Section 209C of <u>Standard Methods</u>, Fifteenth Edition.

Collection Methodology

The decision to use a gravimetric measurement method implied that data collection would have to be by discrete point sampling rather than continuous monitoring. The sampling methodology used was based on a review of similar WES sponsor studies (Nichols, Thompson, and Fass 1978), standard streams suspended sediment load sampling procedures, and experiences of the investigators during preliminary sampling efforts. The methodology was based on vertical depth profiles taken at increasing distances from the dredge along the direction of current flow.

The actual sampling procedure consisted simply of pumping water from the selected depth into 250-ml sample bottles. Current direction and speed were determined for each sample taken using speed and direction meters attached to the sample intake. Salinity of each sample was determined in the laboratory prior to gravimetric analysis.

FIELD STUDY SITES

St. Johns River, Jacksonville

The first field study was conducted in Jacksonville, Florida, during February 1982 (Figure 1). This study directly compared sediment resuspension of conventional and watertight clamshell dredges. Monitoring and sampling of both the watertight and open bucket operations were conducted on 9-11 February 1982.

The dredging work performed during this project was the deepening of the pier basin to 15 feet. Figure 2 shows the area that had already been dredged prior to the time of sampling. Most of this area had been excavated to 18.5 feet. As can be seen, by the time actual sampling was conducted the operation was quite close to the shore and in shallow water. Indeed, the nearby bank, the pier, and the dredge and scows acted to restrict the flow of water within the area between the dredge and the north bank. The current in

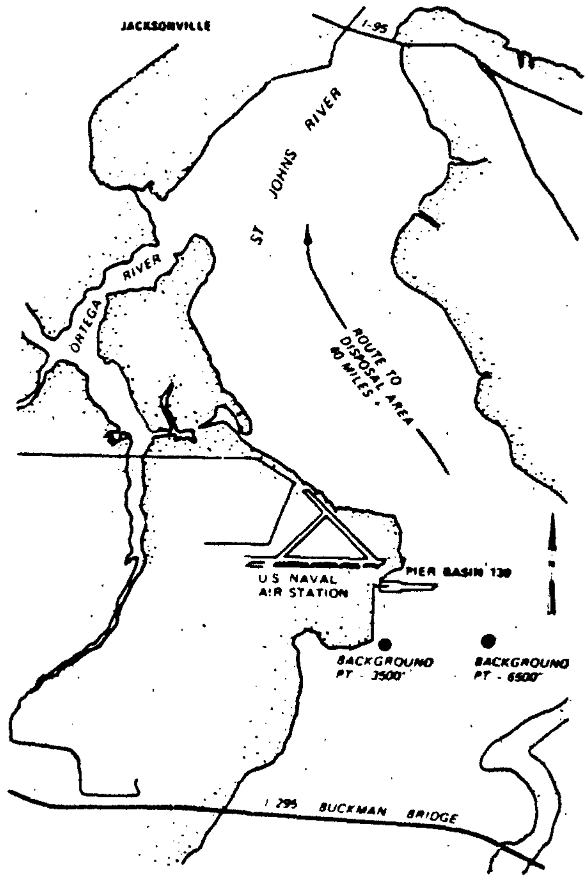


Figure 1. General location map for Jacksonville clamshell comparison

this area was only 0.1 or 0.2 ft/sec. The dredge generally operated for about 10 hr a day (0700 to 1700). This meant a certain amount of flushing could occur during "nondredging" hours. During the period of sampling the nondredging hours coincided with the maximum ebb tide. Subsurface data accompanying the bid invitation characterized the bottom as silt (MH) with a specific gravity of 2.4. Ninety-eight percent of the particles were reported to be smaller than 0.002 in. Subsurface investigation revealed the sediment to be black in color. Inspection of the sediment during sampling confirmed this.

The watertight bucket used (see Figure 3) was a modified Yawn-Williams 13-cubic-yard clamshell-type bucket. The modification consisted of the welding of side and top plates onto a standard bucket. The edge of each half was lined with rubber to ensure a watertight seal. A rectangular opening was left in the top of the box for the pulley, and to allow air to escape during submersion. The contractor estimated that the addition of the sides and top probably increased the bucket's capacity to around 15 cubic yards. The open clamshell bucket used on 10 February was a standard 12-cubic-yard Yawn-Williams bucket.

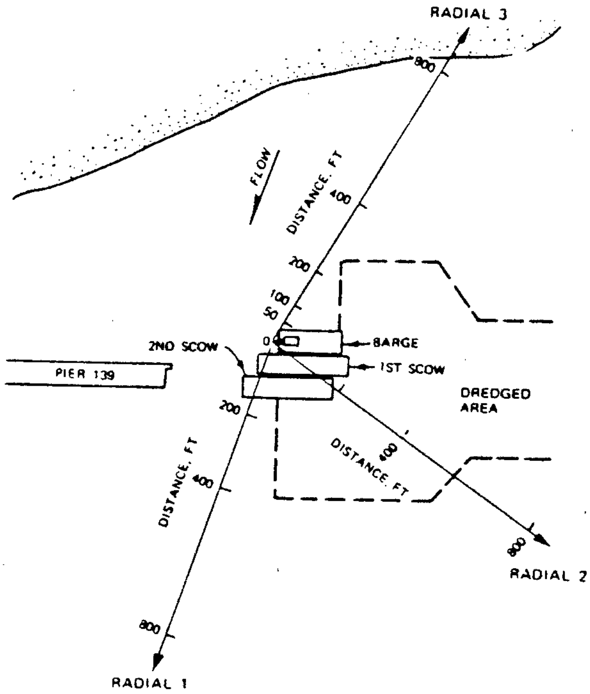


Figure 2. Sampling radials, Jacksonville clamshell comparison

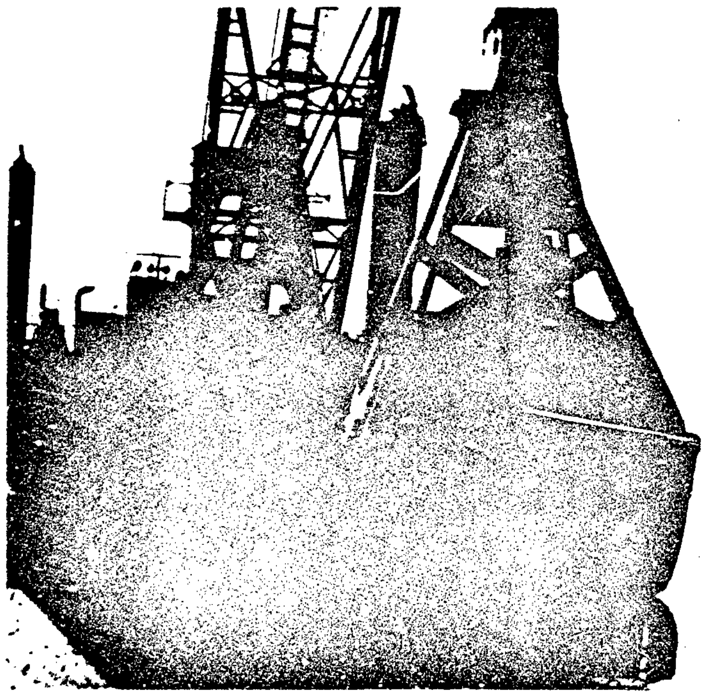


Figure 3. Watertight clamshell bucket, Jacksonville clamshell comparison

The excavation was accomplished using standard bucket dredging procedures. Once anchored, the bucket was positioned above the water and lowered open onto the material to be dredged. The operator found that the watertight bucket had to be lowered more slowly at the start of the descent to allow the air trapped in the bucket to escape. Penetration of the sediment was achieved solely by means of the bucket's weight. Once the jaws were closed, the bucket was lifted to the height of the scow, swung over to the scow, and the bucket emptied. The bucket was then swung back to a position one bucket's width over and again lowered for another grab. Due to the shallow water depth, this cycle of lowering, digging, raising, swinging, dumping, and return took only about 45 seconds. The dredge would clear a "cut" about 60 feet wide before moving forward 4 or 5 feet to the next "cut." The dredge usually went over a cut twice to ensure proper depth. The average hourly production during the sampling period was 770 cubic yards per hour.

Barnard (1978) stated that the resuspension of sediments during bucket dredging was caused primarily by the impact, penetration, and withdrawal of the bucket from the bottom sediments. Secondary causes were felt to be loss of material from the bucket as it was pulled through the water, spillage of turbid water from the top and through the jaws of the bucket as it broke the surface, and inadvertent spillage while dumping. Barnard also reported that the Japanese had developed a watertight bucket that caused 30-70 percent less turbidity in the water column than a similar open bucket. Barnard attributed this to a 35-percent reduction in loss from the bucket as it was lifted through the water column and swung over the hopper or scow.

The sampling radials used during data collection are shown in Figure 2. Data collection was based on the previously described sampling methodology. Due to the shallow depths, fewer samples were taken than originally planned. Background samples were taken each day at locations 3500 feet south of the operation along the shoals, and 6500 feet southeast in the main ship channel. The background sample locations are shown in Figure 1. All samples taken were returned to WES for gravimetric analysis.

James River, Virginia

WES's second field study was conducted in conjunction with Norfolk District's James River Demonstration Project. The James River, during the period 1967 to 1975, was polluted with a chlorinated hydrocarbon pesticide known as Kepone. The Kepone became adsorbed to the fine-grained, organic-rich sediments of the river (Hugget, Nichols, and Bender 1980), with the bulk accumulating in the zone of maximum turbidity in the middle estuary. Within this zone, Kepone is stored in sites of high deposition, i.e., in dredged ship channels, tributary mouths, and reaches of wide cross section where tidal currents are reduced. Because of the Kepone, the Norfolk District, Corps of Engineers, decided to conduct a dredging demonstration project as part of the normal maintenance of the James River Channel. The goals of the demonstration were to achieve containment of a layer of polluted sediment; minimize resuspension of sediment at the dredge head; and remove the sediment at in situ density. In order to achieve these goals, a dustpan suction head was specially adapted and

fitted on a typical hydraulic pipeline dredge (see Figure 4). The dredge was operated in the dustpan mode using a dredging method designed to obtain precise positioning of the suction head within the specified layer of polluted sediment. The dredge was later operated as a conventional cutter suction dredge under similar conditions for comparison with the dustpan arrangement. The Norfolk District developed an extensive monitoring program to evaluate the relative effectiveness of each dredge type and to determine any changes in the Kepone level, both dissolved and adsorbed. The IOMT field studies were made in addition to these efforts.

Sampling took place on 27-29 May 1982 for the Dustpan Head Phase and on 9-14 June 1982 for the Cutterhead Phase. The location of both these sampling efforts is shown in Figure 5. This area is also the "turbidity maximum" of the James River and was shown to contain the highest level of adsorbed Kepone. The channel in this area is 300 feet wide, with a project depth of 25 feet. In both phases the dredge actually excavated to 28 feet. Subsurface investigation revealed the material to be excavated as underconsolidated silty clay (CH) with an average moisture content of 144 percent and a wet unit weight of 84 pounds per cubic foot. Liquid limits were greater than 100 with plastic indices greater than 60.

Figures 6 and 7 show the sampling pattern for each phase. The basic difference results from the collection constraints imposed by the dredging methods. During the dustpan phase the dredge moved across the channel, and was controlled by wires anchored in mid-channel. This limited the collection area to the edge of the channel for the 100- to 400-foot interval. During the cutterhead phase, movement around the dredge was less restricted. Additionally, the cutterhead could only dredge half the channel at a time, making estimates of plume location easier.

The data collected along the radials were supplemented by data collected in other phases of the overall demonstration project. As part of the evaluation being conducted by Norfolk, a dredgehead collector was attached to the two different heads. This collector consisted of a line of tubes which allowed in situ water samples to be pumped to the deck of the dredge. The samples were pumped into a tank on deck and a transmissometer located within the tank used to determine the turbidity at the point of dredging. The IOMT sampling team also used this device to take additional samples for gravimetric analysis. This device is depicted in Figures 8-10.

PRELIMINARY RESULTS OF DATA ANALYSIS

Jacksonville Clamshell Comparison

The initial analysis of the data from the Jacksonville field study was accomplished by comparing suspended sediment levels along each of the three radials shown in Figure 2. The amount of suspended sediment, by radial, found at each sample point is given in Figures 11a, b, and c. These values are adjusted for the daily background levels for the appropriate depth. A reading of zero therefore means the amount of suspended sediment did not exceed the background for that day and depth.

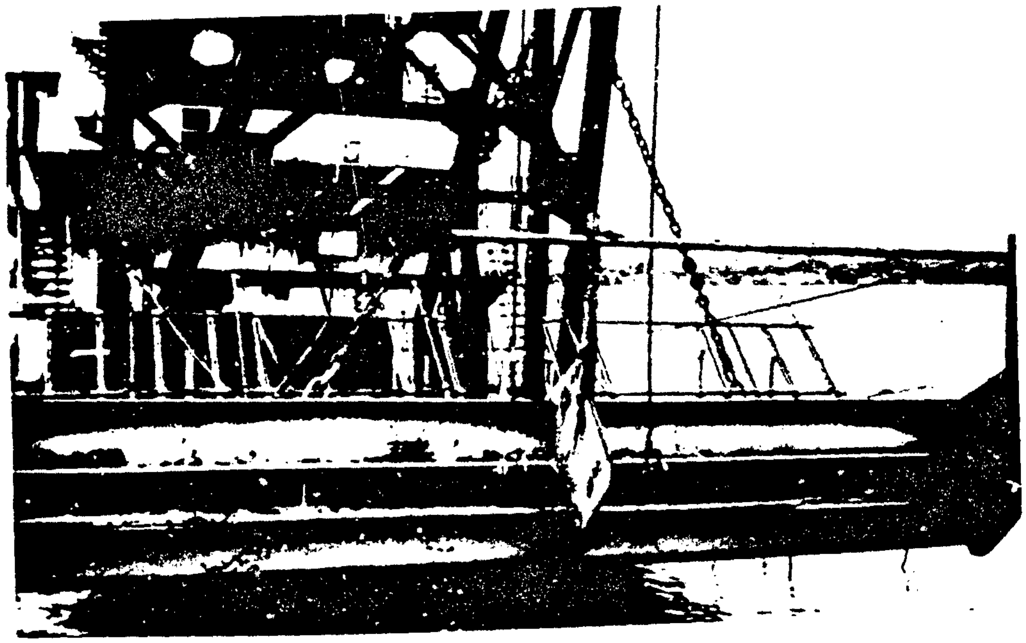


Figure 4. Modified dustpan head, James River Demonstration Project

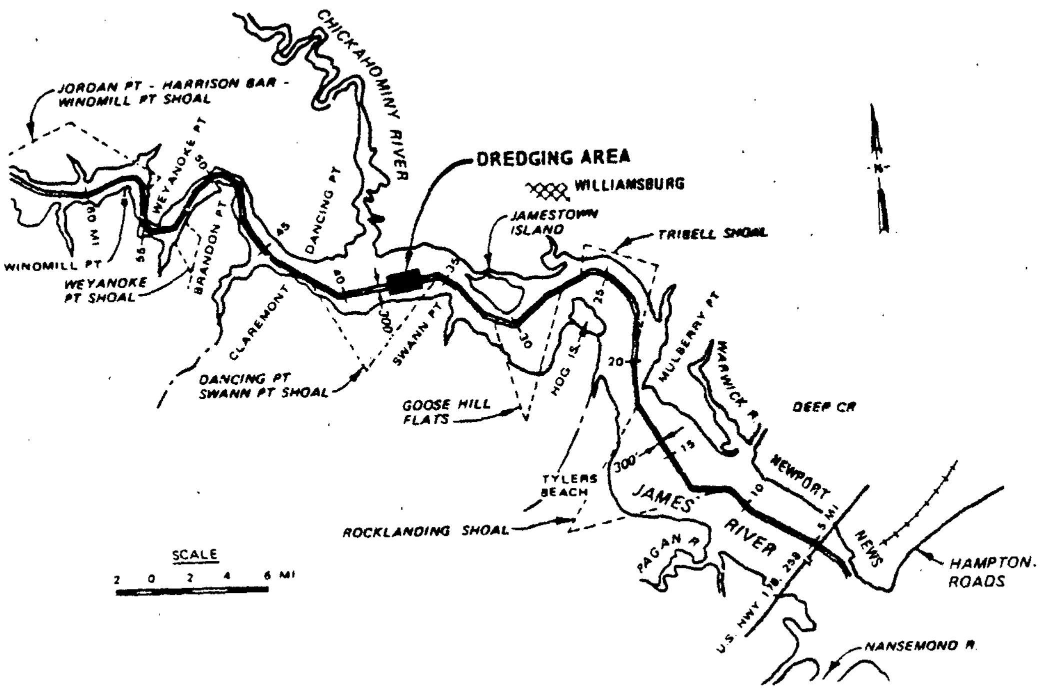


Figure 5. General location map for James River Demonstration Project

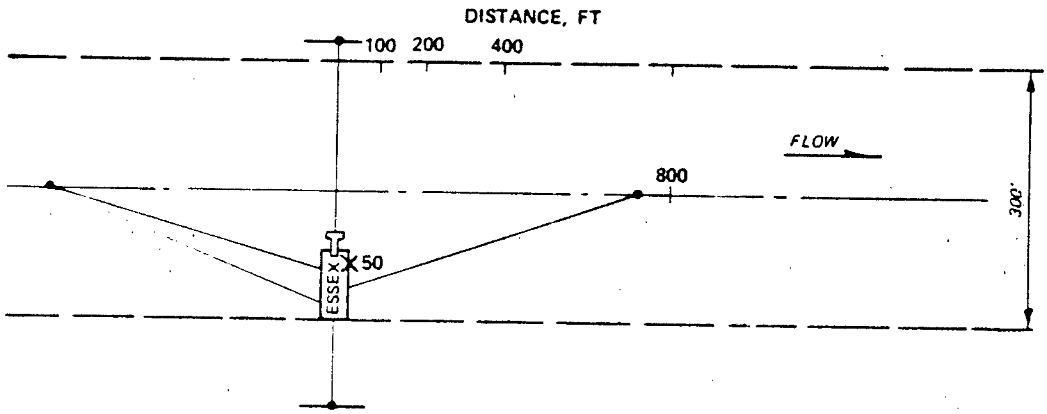


Figure 6. Sampling pattern, dustpan phase, James River Demonstration Project

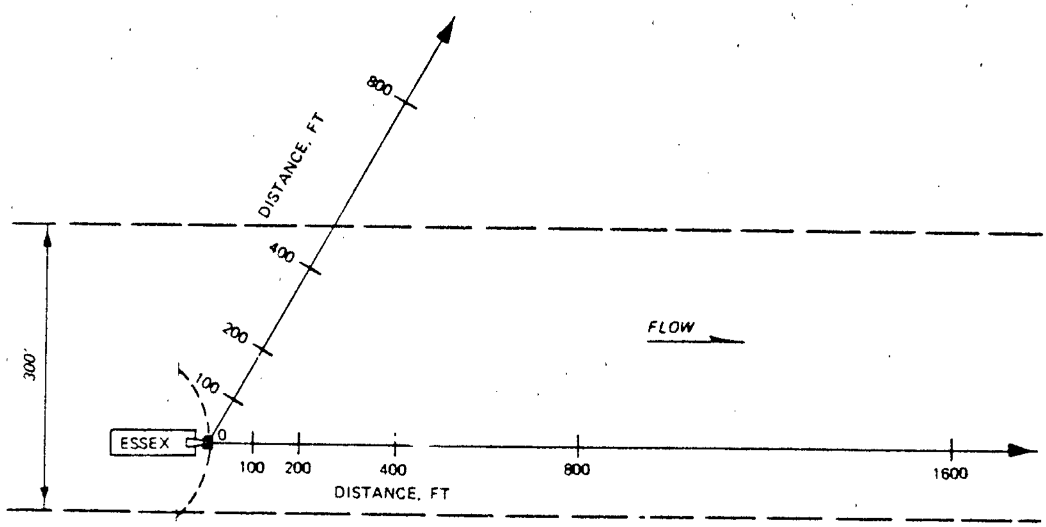


Figure 7. Sampling pattern, cutterhead phase, James River Demonstration Project

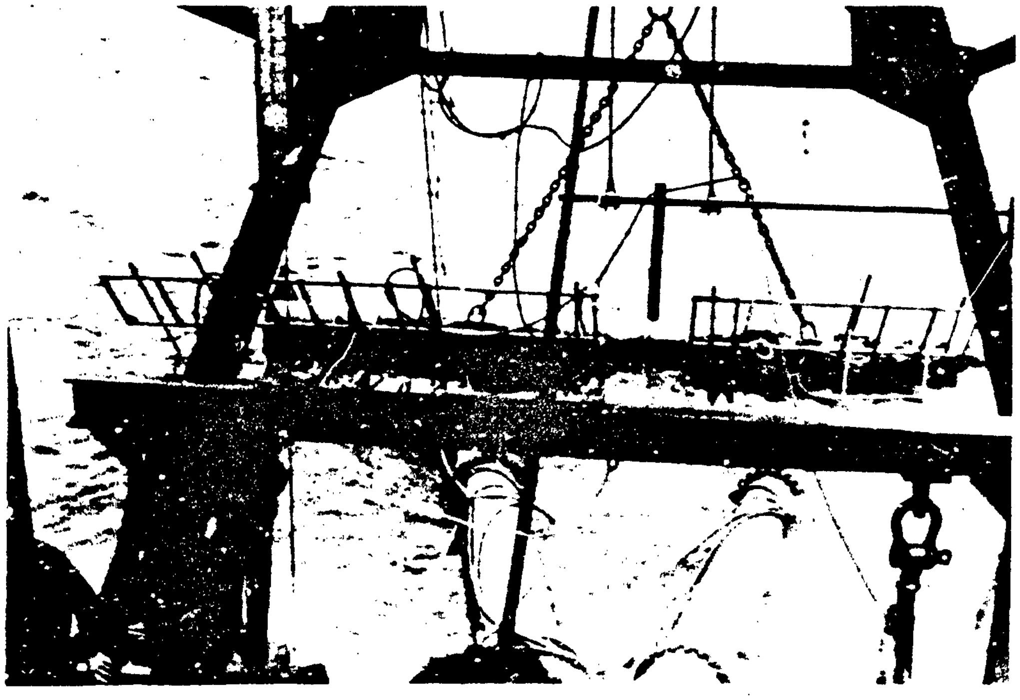


Figure 8. Dredgehead collector, dustpan head, James River Demonstration Project

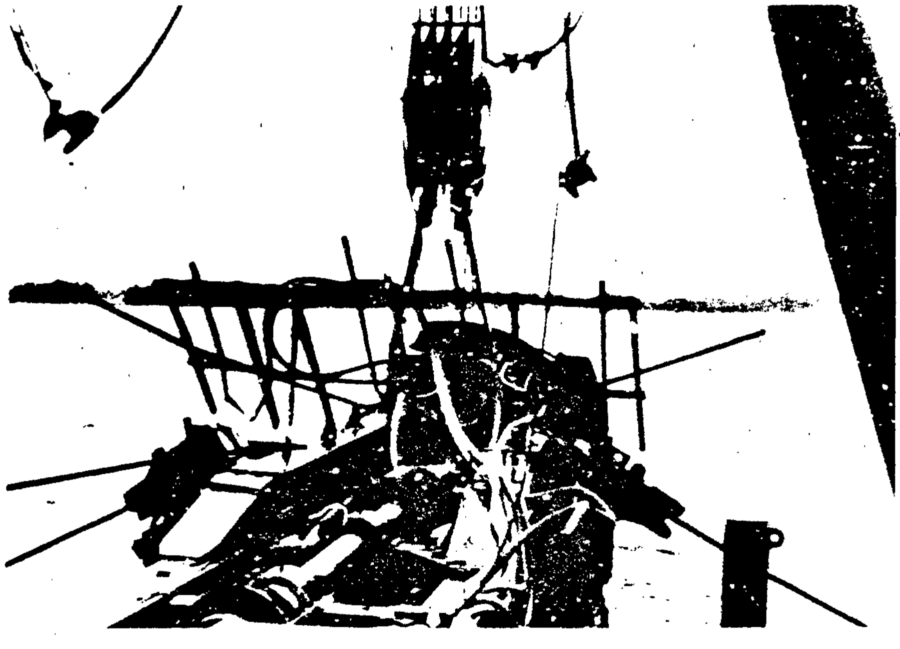
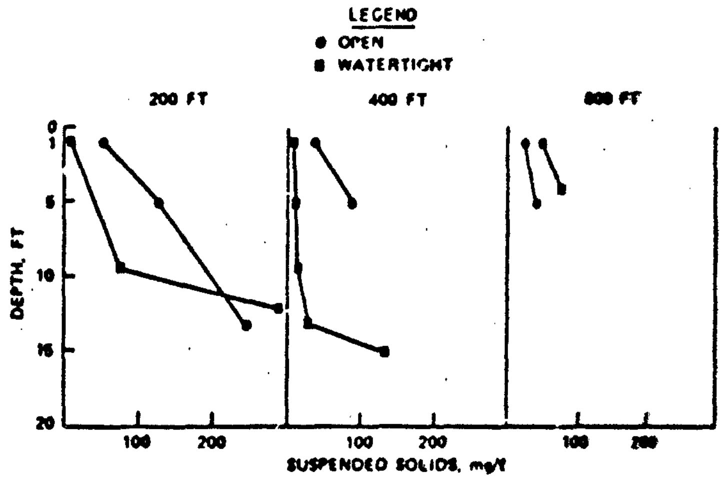
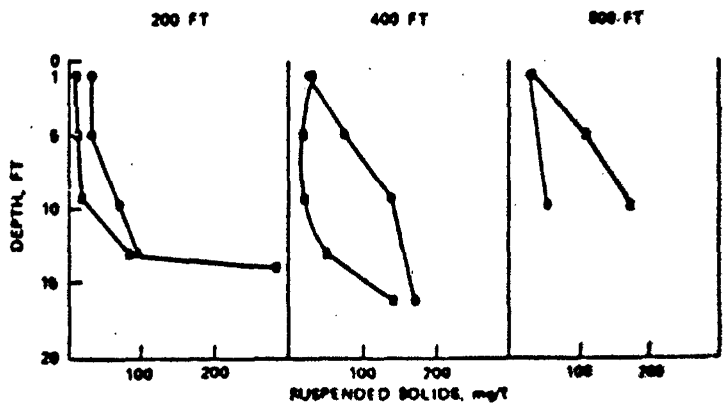


Figure 9. Dredgehead collector, cutterhead, James River Demonstration Project

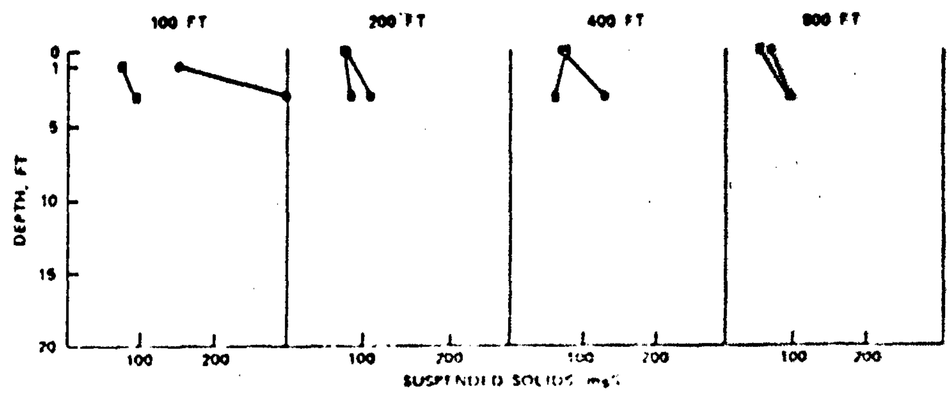
Figure 10. Collection tank and transmissometer for dredgehead turbidity, James River Demonstration Project



a. Radial 1



b. Radial 2



c. Radial 3

Figure 11. Suspended solids levels, Jacksonville Clamshell Comparison

As expected, the results along each of the radials were somewhat different. Along radials 1 and 2 the watertight bucket seemed to produce reduced resuspension in the upper water column at distances closer than 400 feet. Along radial 3 the watertight bucket seems to offer generally reduced resuspension throughout. The 800-foot readings for the watertight bucket along radials 1 and 2 appear to be anomalous, since in addition to reversing the trend of lower resuspension for the watertight clamshell they also reflect an increase from the 400-foot reading. The reason for this is not as yet apparent; however, it may be due to increased effects of the current at the sample points farther away from the point of dredging combined with a decrease in sample depths from 400 to 800 feet.

Figure 12 shows the average suspended sediment level taken along each radial. Along both radial 1 and 2 there appears to be a marked increase in sediment resuspension as we approach the bottom. Table 1 depicts this phenomenon more clearly. Table 1 presents the average values of suspended sediments, by radial, for each type clamshell. These readings are adjusted for background. The differences between average values were found to be statistically significant at the 95% confidence level.

The data in Table 1 indicate that the watertight clamshell offers a marked advantage in the upper water column over the open clamshell. This would tend to support Barnard's (1978) contention that the advantage of a watertight clamshell is the reduction in losses as the bucket moves

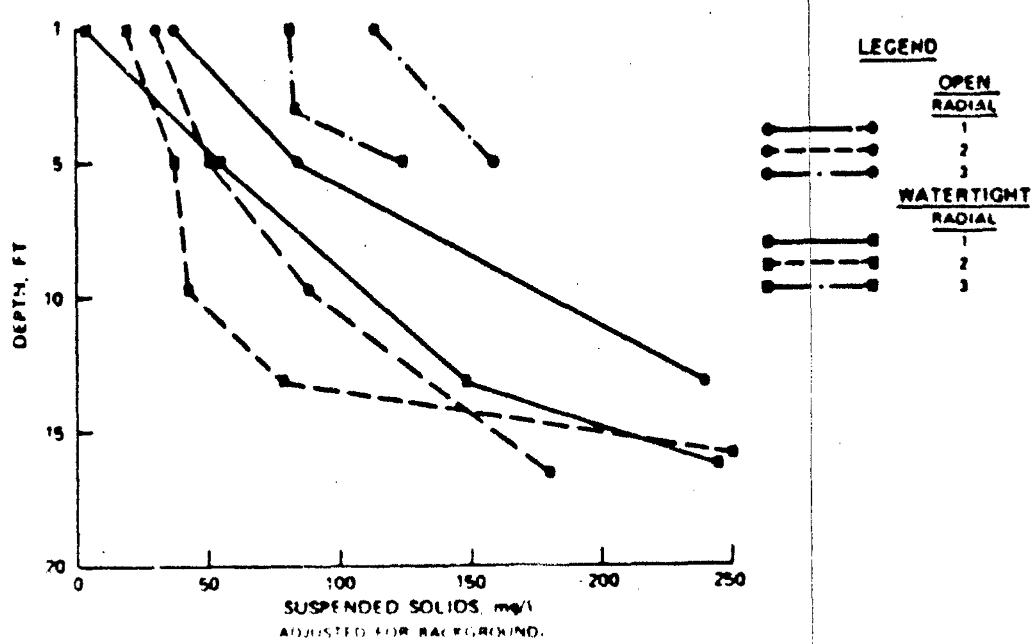


Figure 12. Average suspended sediment level, by radial, Jacksonville Clamshell Comparison

Table 1. Average Adjusted Suspended Sediment Levels, in mg/ℓ

RADIAL	WATERTIGHT CLAMSHELL	OPEN CLAMSHELL
	Upper Water Column	
1	27	123.25
2	35.6	61.0
3	80.6	133.3
	Near Bottom (Within 5 feet)	
1	233	146.6
2	300	122.0
3	N/A	N/A

through the water. Table 1 also tends to confirm that the major cause of turbidity is the penetration, digging, and withdrawal of the bucket. Figure 13 shows a scale drawing of bucket size to water depth in the channel. As the bucket is withdrawn, bottom material, particularly in the case of silts, will slide into the excavated cut. In fact the dredge usually had to make at least one additional pass to remove this material. This leads to an unusually high level of turbidity in the cut. Since the cut was perpendicular to the current flow, "flushing" of resuspended sediment was more difficult.

James River Demonstration Project

The site conditions for the James River Demonstration Project were different from the Jacksonville Clamshell Comparison. All dredging was conducted in the main channel where the full effect of the tide and current was a factor. As shown in Figures 6 and 7, the primary collection efforts were taken "downstream" relative to the current. As indicated by Figure 7 only one additional radial was taken during the cutterhead phase. This was to check dispersion outside of the main current flow. As seen in Figure 6, due to the unconventional method of dustpan operation and the additional cabling, positioning of the sample points was more difficult during the dustpan phase. Given the general uniformity of sampling and site conditions and the larger number of data points, average values provided more insight than individual plots.

Two types of resuspension data are analyzed: that collected by the dredgehead collector and that collected along the current radials. Both data sets are considered in comparison and characterization of the two dredging methods. Table 2 summarizes the results of the two dredgeheads using only samples collected by the collector system mounted on the dredgehead. These data do indicate a difference in suspended sediment levels at the point of dredging. This difference has proven to be statistically significant at the 95% confidence level. It had been hoped that the dustpan head would reduce the amount of sediment resuspended at the point of dredging. The data in Table 2 appear to indicate otherwise. It is unclear whether this departure from the expected was caused by the equipment or by the operating techniques. The contractor retained by Norfolk District to conduct and evaluate this project attributed this departure in his preliminary report to the better

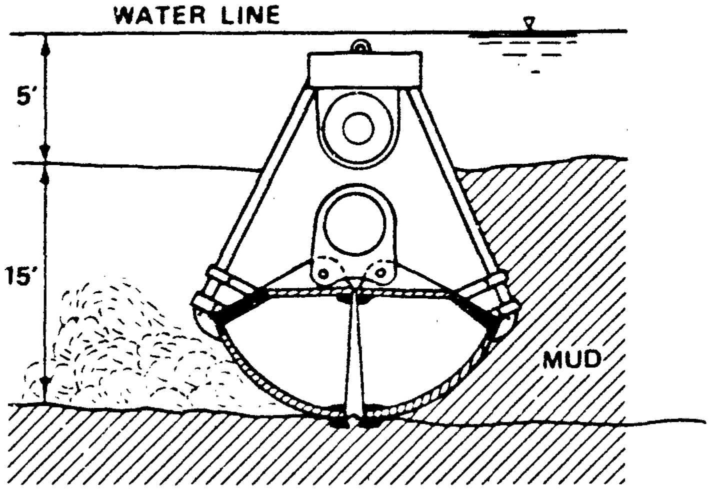


Figure 13. Schematic of watertight clamshell bucket operation, Jacksonville clamshell comparison

Table 2. Summary of Results for the Dredgehead Collector

	DUSTPAN	CUTTERHEAD
Average suspended sediment level, adjusted for background (mg/ℓ)	71.6	40.5
Average current speed (fps)	1.5	0.96
Average salinity (μmho)	371.4	199.5
Average wind speed (fps)	14.6	10.7

hydraulic radius of the cutterhead suction pipe and the difficulties in maintaining a free flow of material through the dustpan (McManus 1982). Another factor to be considered was the dredging technique used with the dustpan during this study. In this study, the dustpan head was operated perpendicular to the current flow. This method was used to allow more exact positioning of the dredgehead. By operating in this manner, the dredge was always moving into a turbidity cloud. The cutterhead was operated generally parallel to the flow, and, depending on its orientation. the current could carry the plume either toward or away from the collection tubes. Indeed, preliminary analysis with respect to current direction shows that while the average level of suspended sediments detected by the dredgehead collector is basically unchanged for the dustpan head, it is markedly affected by current for the cutterhead.

Figure 14 shows the average values of suspended solids for all depths at a given distance. The total average background level was basically the same for both dredges during the sampling periods. These data indicate that while the dustpan may cause more suspended solids near the point of dredging, the cutterhead seems to cause higher suspended solids levels at the greater distances from the point of dredging. Figures 15 and 16 are schematic representations of the average values for each depth and distance sampled. These values

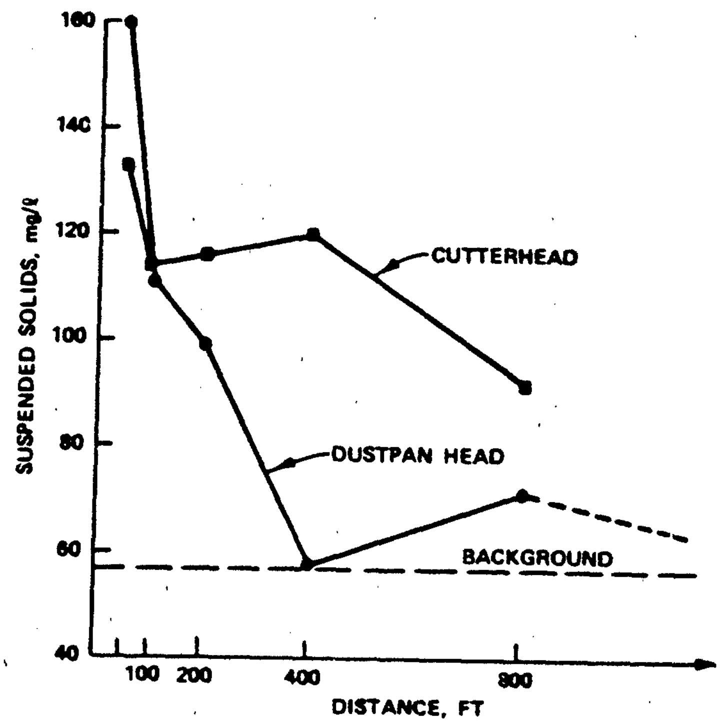


Figure 14. Depth-averaged suspended sediment levels, James River Demonstration Project

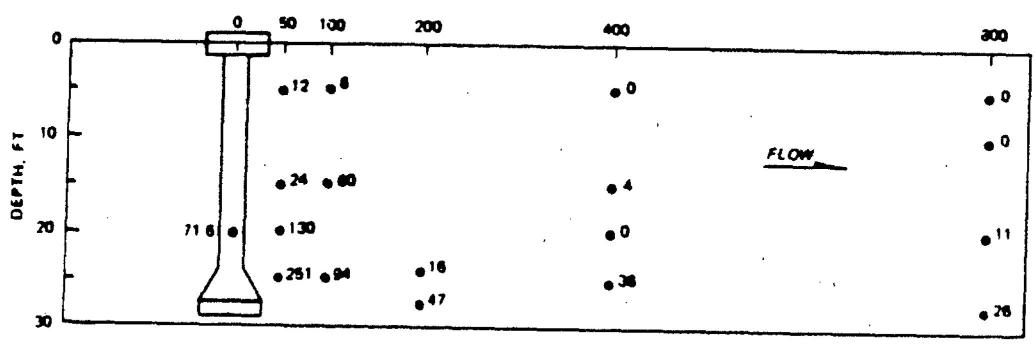


Figure 15. Average suspended sediment values (mg/ℓ), dustpan phase, James River Demonstration Project

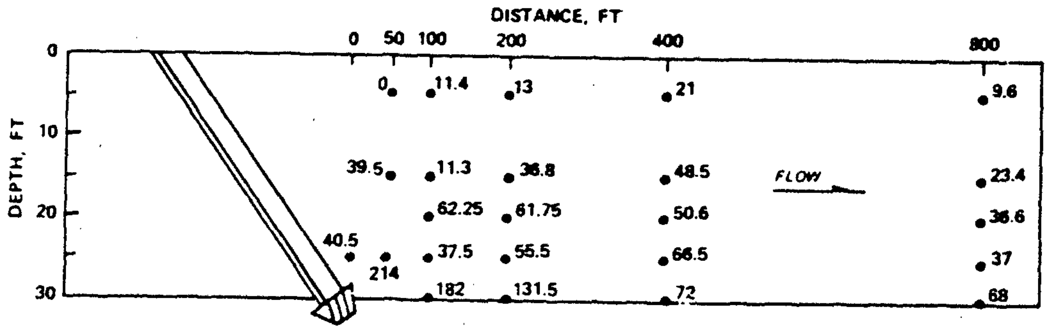


Figure 16. Average suspended sediment values, cutterhead phase, James River Demonstration Project

are adjusted for the average background value for each depth. Again the cutterhead resuspension appears to be greater beyond 100 feet than the dustpan. Also, the dustpan averages (Figure 15) show a uniform distribution of sediment concentrations, while the cutterhead averages (Figure 16) show no such uniformity, other than a general top to bottom increase. The cutterhead does, however, regain some uniformity beyond 400 feet. Figure 17 is a graph of these averages superimposed. The different levels of suspended solids with depth can be more clearly seen in this figure. The dustpan (other than for the 50-foot readings) shows a linear increase in concentrations with depth. The cutterhead appears to have an exponential increase with depth.

The apparent difference in resuspension characteristics of the two dredges may be due to several factors. The most significant may be the basic difference in the way the dredges excavate the sediment. The dustpan plows through the sediment, disturbing the particles, and allowing more to escape due to poorer suction. This resuspended sediment is then carried away by the current and settles fairly quickly. In contrast, the action of the conventional cutterhead imparts a greater kinetic energy to the sediment so resuspended particles tend to travel farther. Additionally, the particles may be "flung" upward and then settle back again, giving the nonuniform distributions observed. This idea is supported by Huston and Huston (1976) research on cutterheads. He concluded that by slowing the rotation of the cutter, or even by removing it and using direct suction, turbidity could be reduced. Another possibility may be sampling differences. The data collected during the cutterhead phase have a high probability of being taken from the center of the plume generated by the dredge (Figure 7). The restrictions imposed by the dustpan method of operation (Figure 6) made center of plume sampling more difficult. The sampling for the 100- to 400-foot distances may have captured only the edge of the plume for this case. Other possibilities are differences in environmental factors during the sampling phases such as current speed.

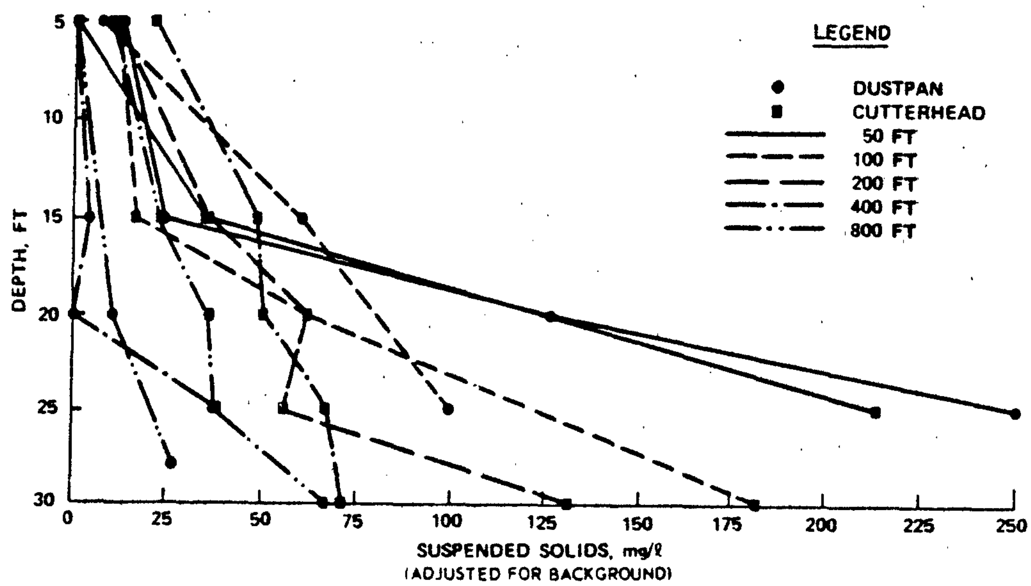


Figure 17. Average suspended sediment levels, by depth and distance, James River Demonstration Project

CONCLUSION

It must be emphasized that this paper has presented an overview of research planned and emerging results based on a preliminary analysis. Much analysis and interpretation of data remain to be done to resolve some of the inconsistencies discussed. There is also the investigation and correlation of production and site factors still to be performed. However, the following tentative conclusions can be drawn:

a) the watertight clamshell does appear to reduce the amount of resuspended sediment in the upper water column, as compared with a conventional open clamshell,

b) the dustpan head shows little advantage over conventional cutterhead suction dredges, and

c) the basic sampling methodology developed is valid and can provide valuable insights into the sediment resuspension characteristics of dredge types.

WES will build on the experience and insights gained during these field studies and conduct further field study during the next two years to obtain additional data on the operation of existing dredge types and, when possible, to evaluate new methods or equipment. It is hoped these field studies will play a major part in our overall goal of predicting and controlling the resuspensions of contaminated sediments.

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BOTTOM SEDIMENT DREDGE "CLEAN UP"
- PRINCIPLE AND RESULTS -

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PROBLEMS OF BOTTOM SEDIMENT DREDGING

Secondary Water Pollution

Most secondary pollution during dredging is caused by suspension of the bottom sediments. There are two main causes of the suspension. The first is disturbance caused by movement of the suction equipment. The amount of the disturbance is determined by the shape and moving velocity of the suction equipment. The disturbance reaches a large volume when moving velocity is over a certain value. The second cause for disturbance is water currents during suction. When the pump suction is set in the bottom sediments or sludge, at first the pump entrains those sediments around the suction mouth and gradually forms many stream-lines around the suction mouth. These stream-lines disturb the surface of sludge adjacent to them. As the suction mouth moves, some of the entrained material is lost into the water.

This disturbance is shaped like a bell, with its center located at the center of the suction equipment. As it is shifted higher, spreading of the disturbance increases. Therefore, we should change our former thoughts about suction equipment in order to prevent the occurrence of disturbance and corpuscular suspension.

Complete Removal

Complete removal of bottom sediments containing noxious materials is desirable but difficult to obtain in actuality.

Bottom sediments left in suspension after dredging will remain for a long time in low density. Elimination of these suspensions is very difficult. These sediments are left in suspension by two actions. These two actions are explained below:

a. Before sucking viscous bottom sediments, short-cut flows of low viscous materials such as water and low density bottom sediments are caused around the suction mouth, and, as a result, bottom sediments under the suction mouth remain undredged.

b. Bottom sediments from undredged areas flow into the dredged area during and/or after dredging. When this stratum of bottom sediments is thick, the volume of sediments that flow into the dredged area cannot be ignored.

The bottom sediment dredging method generally adopted today is the use of spuds and a ladder. In this case, the ladder will be fixed at a specified level, creating difficulty in complete removal of sediments accumulated on the uneven sea bottom. The generally accepted concept that high-density dredging is the best should be reviewed in order to minimize the residuals of bottom sediments. It cannot be denied that high density dredging is desirable. However, high-density dredging is only applicable when removal of sediments can be attained as completely as possible. Therefore, in some instances, careful dredging work has to be performed that sacrifices high-density dredging.

It is desirable if dredging can be accomplished while minimizing resuspension of sediments and reducing the amount of material left behind, yet maintaing high-density production. However, we should always be careful that the environmental effects are not neglected in an attempt to attain high-density production.

Applications of Conditions and Characteristic Variations of Bottom Sediments

It is easily understood that the sediments to be dredged are very unstable and the dredging efficiency mainly depends on the fluidity of the bottom sediments.

Therefore, regardless of the characteristics and conditions of the accumulated sediments, it is necessary to have dredging equipment with adequate adaptability at the suction mouth of the dredging pump. That is to say, if suction equipment can be developed that can collect a constant quantity of sediments, regardless of the depth of the accumulated sediments, and average the mixture of the various characteristics of sediments, we can provide a constant supply of slurry to the dredging pump in the stable condition by combining the sensors which can check the conditions of collecting and mixing of the sediments. In order to realize stable collection and mixture of sediment, a constant contact betweeen the suction equipment and bottom sediments is needed.

If the suction equipment can maintain these conditions, we can expect much wider dredging capacity and stable dredging work for all kinds of sediments.

NEW EQUIPMENT FOR SEDIMENT DREDGING

Function Needed as Dredging Equipment

The final purpose of sediment dredging techniques is to remove these sediments completely without polluting the surrounding water.

The suction devices generally used for the pump type dredges include a cutter head or a suction head for cutter suction dredges, and a trailing head for trailing hopper suction dredges.

The main functions of a cutter head are to excavate the sand on the sea bottom and to assist in suctioning and collecting excavated materials. The rolling wings of a cutter head uniformly mix excavated materials with water and guide them into the suction mouth.

A trailing head moves touching slightly on the surface of the seabed. Water flows through the small opening between the bottom of the head and the seabed to the center of the head. At the same time sand at the bottom of the head is sucked into the trailing head.

In order to increase the dredging efficiency, a special type of trailing head is used. Parts of this head are movable, the opening at the back side of the head becomes smaller. By decreasing the size of the opening, inflow of water is minimized. Thus, the dredging efficiency is increased. A study has already been made on this subject. 1)

Another feature of a trailing head is that it maintains a steady contact with the seabed.

The development of suction equipment used at present results from long technical experience. As a whole, they have been so improved that they can operate with a constant performance as well as function in various dredging conditions.

Combining these technical lessons with the various problems regarding sediment dredging, we would like to state hereunder the fundamental conditions necessary for developing the most desirable suction equipment.

The traditional thought about suction equipment is that materials are led into the suction mouth by water currents, in which the existe ce of water currents from outside the suction head is presupposed. At this stage, we propose a different thought: we regard suction equipment as "the collecting equipment of sediment." This is based on the concept that it is better to intercept water currents from outside the equipment, and to wrap these sediments into the equipment in the sediment's original condition. To prevent water pollution and handle the variety of sediment conditions, the collecting equipment should possess the movable wings system that can encompass a large area of sediment. If the collecting equipment has a simple shape such as a bulldozer's blade, it will be of no use.

The most effective method to completely remove bottom sediments of different viscosities is to change these sediments into a uniform density and viscosity. In this manner bottom sediments can be removed completely since the sediments will then flow regularly. Therefore, it is necessary to equip the suction equipment with a mixing device. The mixing device should also enable the smooth movement of water and sediments to the suction mouth. By fitting the suction equipment with the mixing device, we can expect stable operation of the dredging pump and a good dredging result without a remaining undredged portion.

The suction equipment must maintain a constant contact with the bottom sediments. One method to make this possible is to control the contact pressure of all or the suction equipment against the bottom sediments. By controlling the contact pressure, it is possible to control the submerging depth of the equipment in the sediments. In addition, it is possible to dredge the sediments in accordance with the formation of the seabed. The suction equipment should always be in contact with the bottom at a constant angle. In order to do this, the suction equipment has to be equipped with a horizontal controlling device which maintains the angle even if the dredging depth or other conditions change.

In order for the suction equipment to operate efficiently, it is necessary to check the accumulating condition of sediments in front of the equipment, check the collecting condition, and if possible check the flowing condition. It is also necessary to check the generation of turbidity caused by dredging. By using sensors to check these dredging conditions, the most efficient operating conditions can be provided by the operator of the dredge.

Dredging Equipment

Based on the functions listed above, we have developed some new dredging equipment, named CLEAN UP (Figure 1). CLEAN UP is equipped with a movable

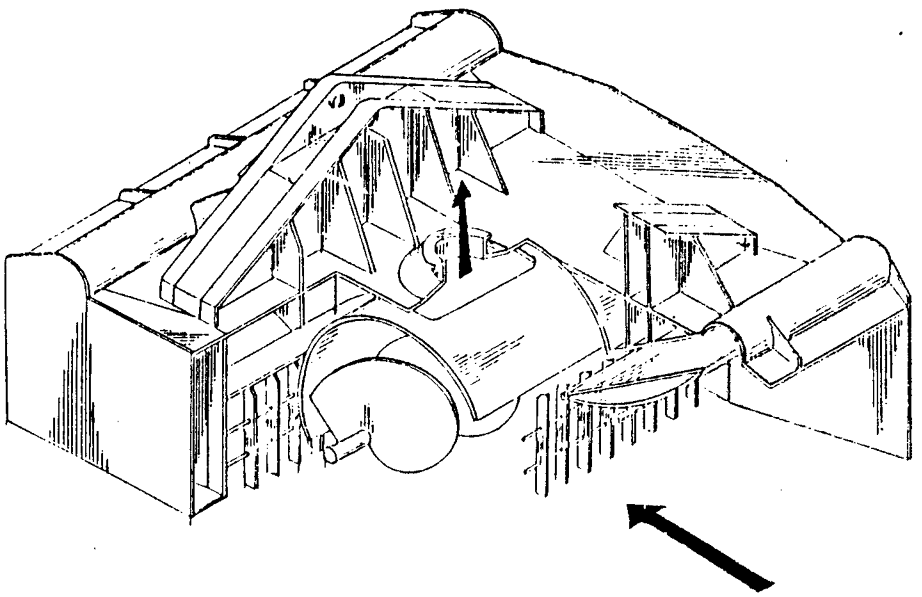


Figure 1. CLEAN UP equipment

wing in front to overlie the bottom sediments, a movable shutter to intercept the inflow of outer water, a mixing device, and sensors to check the dredging conditions. In addition, the equipment can control the contact pressure against the seabed, and keep its position horizontal regardless of depth.

Figure 2 shows the structure of the dredging equipment. A photo of Clean Up is shown in Figure 3.

Dredging Pump

Various types of dredging pumps have already been developed in Japan. The principal ones are pneumatic, submerged centrifugal, piston, and screw. For dredging bottom sediments, the pump must possess the following abilities:

a. Stable suction in high density regardless of the water depth.

b. The ability to transfer constant volume regardless of change of density.

c. Production feasibility of a large capacity.

d. A large passage for rubbish and obstacles.

e. Low equipment and running costs.

Upon examination of these requirements, we chose the submerged centrifugal pump as the most desirable pump for sediment dredging.

As Figure 4 shows, the submerged centrifugal pump is designed for dredging bottom sediments, and consists of a submerged hydraulic motor and a passage large enough for rubbish and obstacles.

This pump (combined with the hydraulic motor) is fixed in front of the dredge's ladder so that the pump is always in the water. The pump is designed to maintain a constant rate of flow regardless of the change of density by controlling the hydraulic pump placed in the machinery room. The rate of flow can be easily changed in accordance with the dredging conditions.

EXCLUSIVE DREDGE

For dredging bottom sediments in Japan, some exclusive dredges have been constructed. These dredges are equipped with suction equipment and dredging pumps for bottom sediments. The main features of the typical exclusive dredges are shown in Table 1. Figure 5 shows the general arrangement of CLEAN UP NO. 3. Figure 6 is the photograph of CLEAN UP NO. 3.

RESULTS

Actual Results of Bottom Sediment Dredging

The number of dredging jobs using CLEAN UP dredging equipment totaled 45 at the end of 1981, and the dredged volume has amounted to about 2,200,000 m^3.

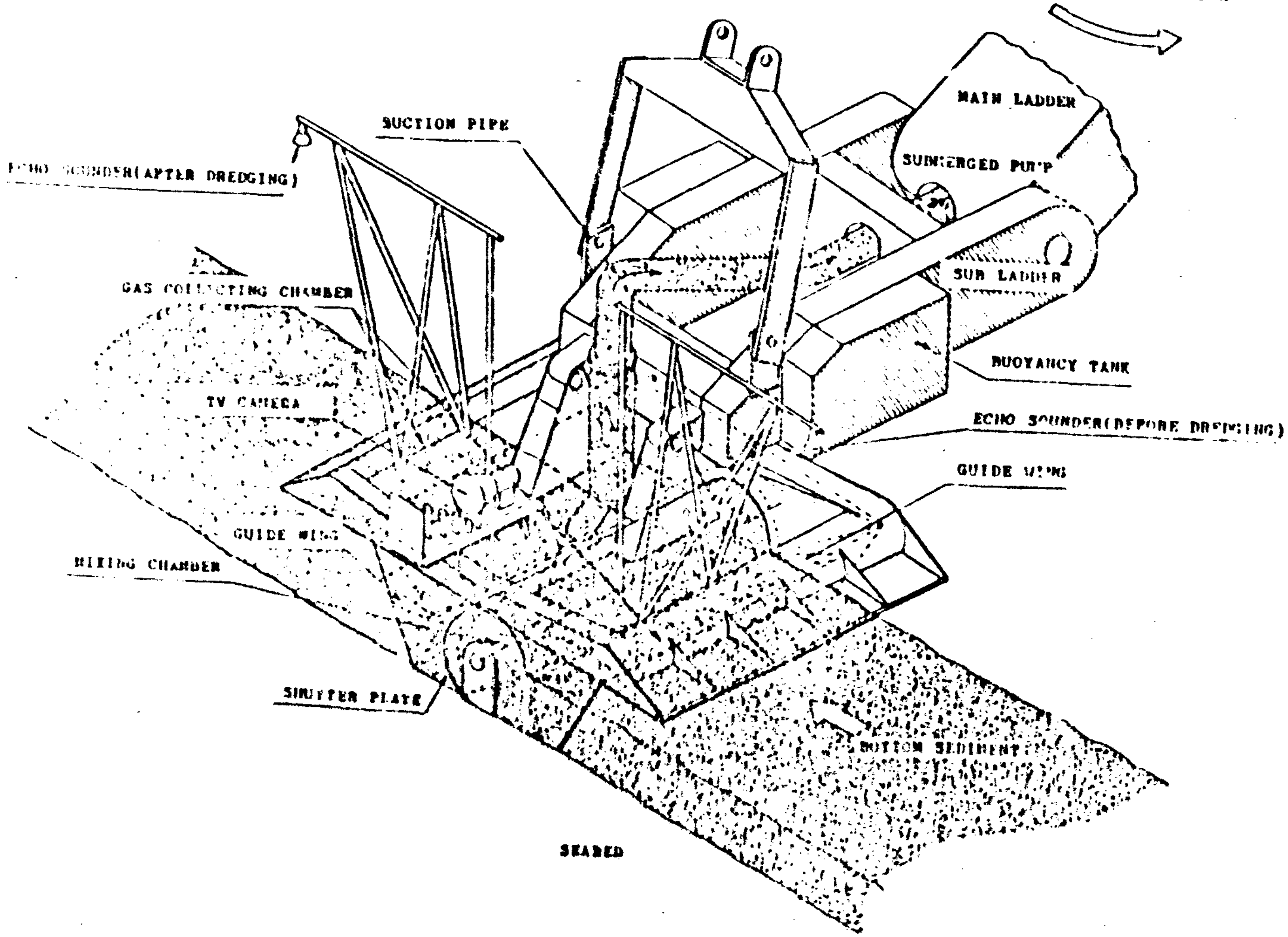


Figure 2. Structure of dredging equipment

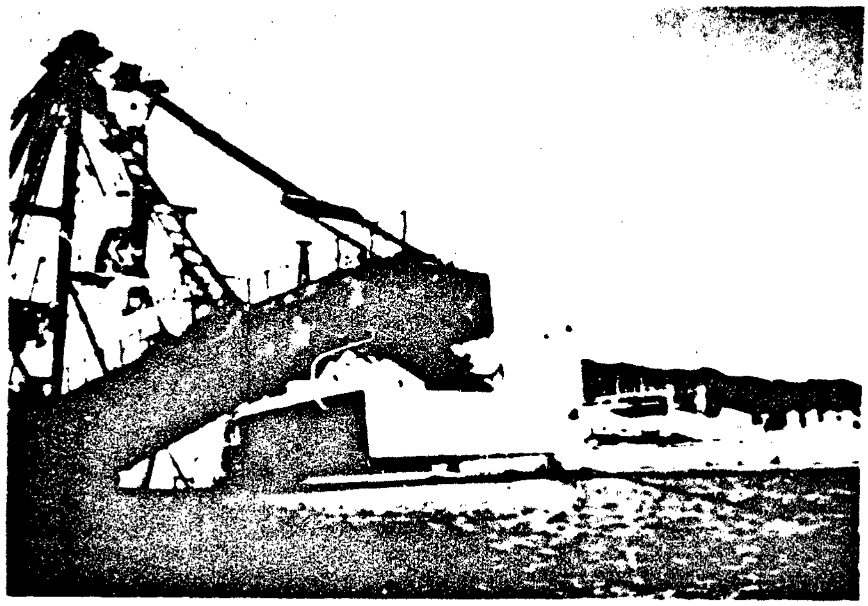
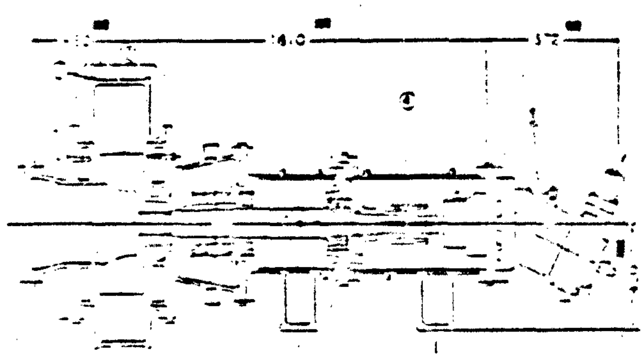


Figure 3. New suction equipment CLEAN UP



1 casing
2 impeller
3 hydraulic motor
4 coupling

Figure 4. Submerged centrifugal pump

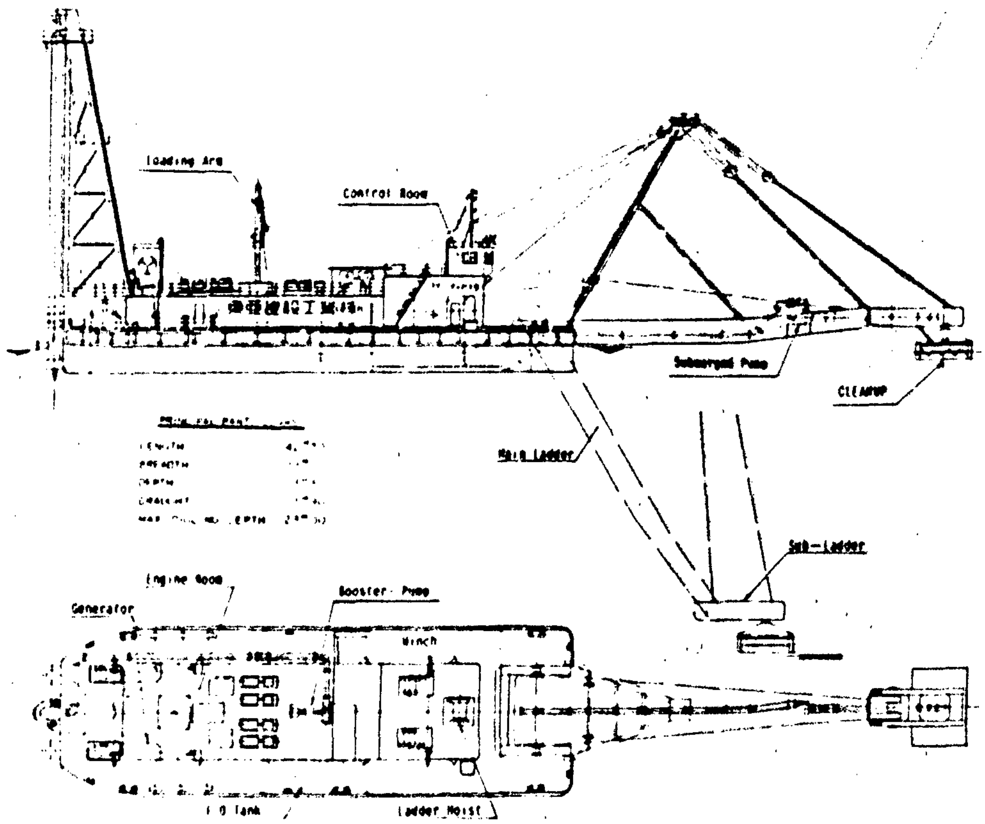


Figure 5. General arrangement of CLEAN UP No. 3

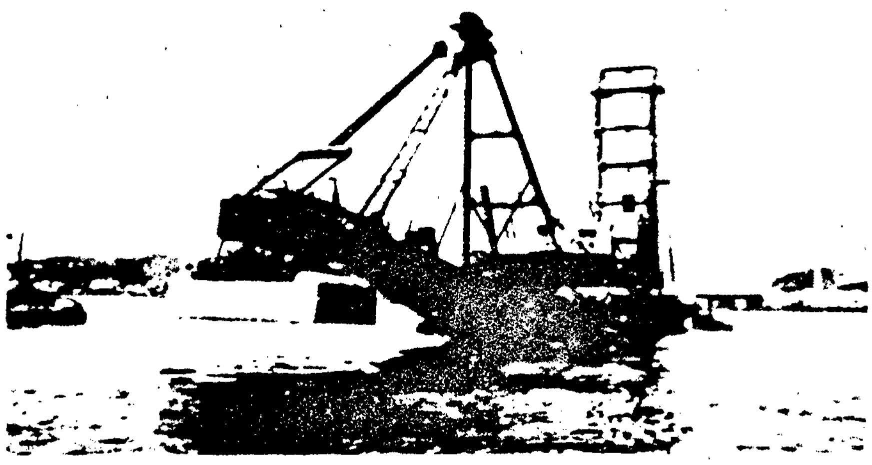


Figure 6. CLEAN UP No. 3

Dredging soils have been mainly soft mud and sand, containing various noxious materials, for example, mercury, cadmium, PCB, and oily and organic substances.

Table 2 shows the list of dredging work and removal of bottom sediments.

Relations Among Dredging Conditions, Turbidity Generation, and Dredging Density

The swing velocity and cutting depth of soil per swing are related to turbidity generation and dredging density. When using CLEAN UP suction equipment, 3 to 4 m/min of swing velocity is best for minimizing turbidity generation. When the swing velocity is over 3 to 4 m/min, turbidity generation increases.

The adequate cutting depth of soil is 0.4 to 0.5 m. When the cutting depth exceeds this value, turbidity generation increases and the possibility exists of sediments left undredged.

The greater the swing velocity and cutting depth, the greater the dredging density will become. Turbidity generation should be within permitted limits by controlling swing velocity and cutting depth. Average density of dredging using CLEAN UP is 30 to 40%.

Turbidity Around the Dredging Equipment

Turbidity around the dredging equipment is always checked through a submersible TV camera. Under normal bottom conditions, the actual value of maximum turbidity is 6 to 8 ppm for sediment dredging. However, the turbidity value sometimes increases up to 80 - 100 ppm during starting and stopping of the pump or changing of the swing direction. In these situations, the turbidity will be minimized by our operating techniques.

Results of Investigations about Generation Unit of Turbidity

Table 3 shows the results of investigations about the generation unit of turbidity caused by CLEAN UP dredges. A generation unit of turbidity is the total dry weight of turbidity that occurred during dredging work per 1 m^3 of the materials dredged from the seabed ($tons/m^3$).

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Table 1. Main Features of Exclusive CLEAN UP Dredges

Dredge	Type	Dimensions (m) L × B × D × d	Main Pump	Booster Pump	Pump Suction Capacity (m/hr)	Max. Discharge Distance (m)	Max. Dredging Depth (m)	Min. Dredging Depth (m)	Remarks
Cleanup No. 1	DE	$26.^{9}\times 10.^{1}\times 1.^{2}\times$ 0.4	Centrifugal Pump 100 PS	--	500	1,000	Under Surface of Water 6.2	1.5	--
Cleanup No. 2	DE	$36.^{0}\times 11.^{0}\times 3.^{2}\times$ 2.0	Centrifugal Oil Pump 147 PS	Centri-fugal Electric Pump 253 PS	0-1,500	1,500	Under Surface of Water 23	2.5	Discharge variable pump with barge loading equipment
Cleanup No. 3	DE	$42.5\times 13.^{4}\times 3.^{3}_{9}\times$ 1.	Centrifugal Oil Pump 147 PS	Centri-fugal Oil Pump 147 PS	0-2,000	1,500	Under Surface of Water 23	3.0	Discharge variable pump with barge loading equipment
Cleanup No. 5	DE	$21.^{5}\times 8.^{0}\times 1.^{5}\times$ 0.7	Centrifugal Oil Pump 50 PS	--	0- 500	500	Under Surface of Water 11	1.5	Discharge variable pump
Cleanup SIRSI	D	$35.^{0}\times 9.^{7}\times 2.^{4}_{6}\times$ 1.	PNEUMA PUMP 300/60 Type	--	300	1,200	Under Surface of Water 15	3.5	Equipped with barge loading system

Table 2

List of Dredging Work and Removal of Bottom Sediments

No.	Client	Description of Works	Contract Period From	Contract Period Until	Dredge Employed	Specifications for Dredging Work: Area (m^2)	Volume (m^3)	Depth (m)	Thickness (m)	Soil Characteristics	Discharge Distance (m)	Efficiency: Pumping Volume (m^3/hr)	Density (%)	Dredged Volume (m^3/hr)	Ooze Treatment
1	Ministry of Transport Port Construction Div. 5	Experiment to invent a special self-propelled dredging barge	Feb. 1973	-	Cleanup SIRSI	1,000	1,000	9.0	1.0	Silt	80	266	41.6	111	Dredging with cleanup SIRSI; transportation with box barge; hydro extraction treatment
2	Kanegafuchi Chemical Industry	Dredging at Takasago East Port	Sep/27 1973	Oct/7J 1973	Cleanup SIRSI Cleanup by night only 18:00-6:00(next day)	19,000	11,240	-4.5 -5.0	0.5 1.0	Upper layer: silt lower layer: clay or sand	1,500	206	25.7	53	Dredging with cleanup SIRSI; settling basin; wastewater treatment; transportation with discharge pipe; solidification treatment
3	Japan Aquatic Resources Protection Association	Experiment for feasibility study on protection works against red water for the year 1973	Feb/17 1974	Feb/25 1974	Cleanup SIRSI	2,400	473	-10.0 -11.0	0.22	Organic dirty soils	Offshore discharge with box barge	197	19.3	38	Dredging with cleanup SIRSI; transportation with box barge; thickener; pumping
4	Mitsubishi Mining & Smelting	Reclamation at Nishiyama port	May/1 1974	Oct/31 1974	Cleanup SIRSI	46,200	58,000	-4.0 -5.0	1.25	Fine sand with silt	300	260	8.8	23	Dredging with cleanup SIRSI; reclaimed area; disposal through buffer tank method; transportation with discharge pipe
5	Ohtsu Paperboard Mfg.	Dredging & removal of ooze for Ohtsu Paperboard Mfg.	May 1974	Oct 1974	Cleanup No. 1	140,00	23,700	1.5 4.5	0.17	Pulp & sludge	887	370	20	74	Cleanup No. 1; hydro-extraction treatment; disposal area; transportation with discharge pipe & solidification treatment
6	Japan Aquatic Resource Protection Association	Experiment for feasibility study on protection works against red water for the year 1974	Oct/18 1974	Nov/24 1974	Cleanup No. 2	12,390	3,717	-3.0	0.30	Organic dirty soils	250	159	22	35	Cleanup No. 2; filtration treatment; disposal pond; transportation with discharge pipe; hydro-extraction treatment; sand carrier with grab bucket
7	Yokka-Ichi Port Administration	Experiment for anti-polution measures at Yokka-Ichi Port	Mar/5 1975	Mar/11 1975	Cleanup No. 2	3,432	2,712	-12.0	0.80	Oily dirty soils	80	600	47.7	286	Cleanup No. 2; transporation with sand carrier with grab bucket; dirty soils reservoir
8	Sumitomo Metal Co., Ltd.	Removal of sludge near No. 8 drainage outlet	Mar/8 1975	Mar/24 1975	Cleanup No. 2	10,500	5,854	-12.0	0.56	Dirty soils with tar	Offshore Discharge with box barge	500	20	100	Cleanup No. 2; box barge; disposal area within the premises
9	Okayama Pref.	Dredging (-5.5m) in front of slipway at Tamashima Port	Mar 1975	Apr 1975	Cleanup No. 2	12,125	18,000	-5.5	1.50	Silty sand	1,500	500	10	50	Cleanup No. 2; transportation with discharge pipe; reclaimed area

(Continued)

Table 2 (Continued)

No.	Client	Description of Works	Contract Period From	Contract Period Until	Dredge Employed	Specifications for Dredging Work: Area (m^2)	Volume (m^3)	Soil Depth (m)	Discharge Thickness (m)	Characteristics	Distance (m)	Efficiency: Pumping Volume (m^3/hr)	Density (%)	Dredged Volume (m^3/hr)	Ooze Treatment
10	Japan Aquatic Resources Protection Association	Experiment for feasibility study on protection works against red water for the year 1975	Aug/25 1975	Sep/30 1975	Cleanup No. 2	5,650	3,140	-2.5	0.70	Organic dirty soils	450	194	29.9	58	Cleanup No. 2; filtration treatment; disposal area hydro-extraction treatment; sand carrier with grab bucket
11	Yamagata Pref.	Pollution prevention dredging at Sakata Port (Area No.2)	Sep/16 1975	Jul/31 1976	Cleanup No. 1	13,675	22,200	-6.0	1.50	Dirty soils with mercury (silt)	870	330	14.8	49	Cleanup No. 1; disposal pond; wastewater treatment through natural sedimentation method
12	The Tokyo Metropolis	Dredging of dirty soils at Takahama Canal for 1976	Dec/22 1975	Mar/31 1976	Cleanup No. 5	2,793	2,100	-3.5	0.75	Silty organic dirty soils	130	300	32.5	98	Cleanup No. 5; tank barge; disposal area
13	Nippon Mining	Dredging & removal of dirty soils at Sagano Seki Port for 1976	May/10 1976	Oct/9 1976	Cleanup SIRSI	58,500	30,700	-5.0	0.50	Silt or sand	485	383	40	153	Cleanup SIRSI; sedimentation pit; wastewater treatment
14	Yamagata Pref.	Pollution prevention dredging at Sakata Port (Area No. 2)	Sep/16 1975	Jul/20 1976	Cleanup No. 1	9,118	14,800	-6.0	1.50	Silty dirty soils with mercury	870	330	14.8	49	Cleanup No. 1; disposal area; wastewater treatment through natural sedimentation method; transportation with discharge pipe
15	Yamagata Pref.	Pollution prevention dredging at Sakata Port (Area No. 2)	Sep/16 1975	Jul/20 1976	Cleanup No. 1	7,207	11,700	-6.0	1.50	Silty dirty soils with mercury	870	330	14.8	49	Cleanup No. 1; disposal area; wastewater treatment through natural sedimentation method; transportation with discharge pipe
16	Yokkaichi Port Administration Association	Dredging & removal of accumulative dirty soils at Yokka-ichi Port (Phase 1 & 2)	Oct/2 1976	Mar/25 1977	Cleanup No. 1 No.2, No.3	226,500	510,900	-6.5 -13.0	0.5 3.3	Oily dirty soils	280 1,300	441	74.3	328	Cleanup No. 1, 2, 3; station barge; dirty soils reservoir; transportation with discharge; wastewater treatment
17	The Tokyo Metropolis	Dredging at Takahama Canal and preparation of disposal area for dredged material	Nov/28 1976	Mar/21 1977	Cleanup No. 5	4,000	7,296	-2.7 -3.5	0.7 0.7	Organic dirty soils	50	180	28.8	52	Cleanup No 5; tank barge; disposal area
18	Japan Aquatic Resources Protection Association	Experiment for feasibility study on protection works against red water for the year 1976	Jan/15 1977	Feb/5 1977	Cleanup No. 2	34,000	9,370	-16 -21	0.3	Organic dirty soils	400	356	37.0	132	Cleanup No. 2; sedimentation barge; filtration treatment; transportation and disposal; hydro-extraction treatment
19	Nippon Mining	Dredging & removal of dirty soils at Sagano Seki Port for 1977	Apr/1 1977	Oct/31 1977	Cleanup SIRSI	32,500	15,800	-5.0	0.50	Silt with fine sand	635	180	16.3	29.3	Cleanup SIRSI; sedimentation pit; wastewater treatment

(Continued)

Table 2 (Continued)

No.	Client	Description of Works	Contract Period From	Contract Period Until	Dredge Employed	Specifications for Dredging Work: Area (m^2)	Volume (m^3)	Depth (m)	Thickness (m)	Soil Characteristics	Discharge Distance (m)	Efficiency: Pumping Volume (m^3/hr)	Density (%)	Dredged Volume (m^3/hr)	Doze Treatment
20	Miyagi Pref.	Sludge dredging & removing for improvement of fishery environment at Kesen-numa Bay for 1976	Aug/26 1976	Nov/25 1976	Cleanup No. 2	57,000	28,500	-4 -7	0.5	Organic dirty soils	350	190	18.6	74.2	Cleanup No. 5; soil carrier with grab bucket; offshore disposal
21	Miyagi Pref.	Sludge dredging & removing for improvement of fishery environment at Kesen-numa Bay for 1977	Jul/12 1977	Oct/15 1977	Cleanup No. 5	26,860	20,820	-5 -7	0.7 1.0	Organic dirty soils	90	190	18.6	74.2	Cleanup No. 5; soil carrier with grab bucket; offshore disposal
22	Japan Aquatic Resources Protection Association	Pilot works for prevention of red water for 1977	Aug/25 1977	Sep/18 1977	Cleanup No. 2	64,500	24,405	-6 -7.5	0.3 0.6	Organic dirty soils	250	180	17.8	32.0	Cleanup No. 2; sedimentation barge; filtration treatment; transportation and disposal; hydro-extraction treatment
23	Yokkaichi Port Administration Association	Dredging & removal of accumulative dirty soils at Yokka-ichi Port (Phase 3)	Aug/10 1977	Feb/14 1978	Cleanup No. 3	210,860	408,300	-9.8 -13.5	0.3 2.5	Oily dirty soils	300	238	73.5	175	Transportation with discharge pipe; transportation with discharge pipe; Cleanup No. 3; station barge; dirty soils reservoir; wastewater treatment
24	Yokkaichi Port Administration Association	Dredging & removal of accumulative dirty soils at Yokka-ichi Port (Phase 5)	Nov/20 1977	Mar/25 1978	Cleanup No. 3	97,600	202,000	-7.5 -8	2.1	Oily dirty soils	837	316	76.9	243	Transportation with discharge pipe; transportation with discharge pipe; cleanup No. 3; station barge; dirty soils reservoir; wastewater treatment
25	Yokkaichi Port Administration Association	Dredging & removal of accumulative dirty soils at Yokka-ichi Port (Phase 6)	Jun/18 1977	Mar/31 1978	Cleanup No. 3	15,500	15,500	-11	1.0	Oily dirty soils	800	268	67.3	181	Transportation with discharge pipe; transportation with discharge pipe; Cleanup No. 3; station barge; dirty soils reservoir; wastewater treatment
26	The Tokyo Metropolis	Dredging & removal of dirty soils in front of Hamarikyu Works for 1978	Oct/26 1977 1978	Mar/31 1978 1978	Cleanup No. 5	22,800	48,300	-4 -4.6	0.5 0.8	Organic dirty soils	56	200	26.0	53.0	Cleanup No. 5; transportation with box barge; disposal area
27	Okayama Pref.	Pollution prevention	Jun/15	Jan/15	Cleanup No. 2	204,500	90,000	-12 -16	0.4 0.8	Oily dirty soils	Offshore discharge with box barge	550	9.0	50.0	Clean No. 2; transportation with box barge; disposal barge
28	Miyagi Pref.	Sludge dredging & removing for improvement of fishery environment at Kesen-numa Bay for 1976	Jul/26 1978	Jan/15 1979	Cleanup No. 3	65,000	51,700	-4 -7	0.8 1.0	Organic dirty soils	Offshore discharge with box barge	350	43.5	169.7	Cleanup No. 3; transportation with box barge; disposal area

(Continued)

Table 2 (Continued)

No.	Client	Description of Works	Contract Period From	Contract Period Until	Dredge Employed	Specifications for Dredging Work: Area (m^2)	Volume (m^3)	Soil Discharge Depth (m)	Thickness (m)	Characteristics	Distance (m)	Efficiency: Pumping Volume (m^3/hr)	Density (%)	Dredged Volume (m^3/hr)	Ooze Treatment
29	The Tokyo Metropolis	Dredging of dirty soils at Shibaura-Nishi Canal & preparation of disposal area for dredged material	Sep/15 1978	Jan/31 1979	Cleanup No. 1 No. 5	11,006	16,860	-2.9	1.5	Organic dirty soils	Offshore discharge with box barge	350	16.0	56.0	Cleanup No. 1 & 5; transportation with box barge; disposal area
30	The Tokyo Metropolis	Dredging of dirty soils at Shiohama Hirahisa Shiomi Canal for 1978	Feb/2 1979	Feb/23 1979	Cleanup No. 5	2,000	2,700	-2.3 -3.0	1.4	Organic dirty soils	Offshore discharge with box barge	320	17.2	55.0	Cleanup No. 5; transportation with box barge; disposal area
31	Okayama Pref.	Pollution prevention work for 1978	Feb/16 1979	Mar/20 1979	Cleanup No. 2	72,900	37,200	-12 -16	0.4 0.8	Oily dirty soils	Offshore discharge with box barge	850	15.0	165.0	Cleanup No. 2; transportation with box barge; disposal area
32	The Tokyo Metropolis	Dredging of dirty soils at Akebono-kita Canal and Tsukishima/Shin-Tsukishima River	Mar/1 1979	Mar/30 1979	Cleanup No. 5	88,005	6,942	-2.4	0.8	Organic dirty soils	Offshore discharge with box barge	300	20.0	60.0	Cleanup No. 5; transportation with box barge; disposal area
33	Okayama Pref.	Pollution prevention work for 1979	Jun/12 1979	Sep/30 1979	Cleanup No. 2	455,200	215,800	-12 -16	0.4 0.8	Oily dirty soils	Offshore discharge with box barge	860	19.8	170.0	Cleanup No. 2; transportation with box barge; disposal area
34	Kobe Steel Co., Ltd.	Removal of soft mud in front of Kakogawa raw material handling berth	Sep/1 1979	Sep/15 1979	Cleanup No. 3	3,100	1,700	-17 -17.6	0.6	Silt	370	500	22.0	110	Cleanup No. 3; transportation with discharge pipe; reclaimed area
35	The Tokyo Metropolis	Dredging work at Tatsumi Canal for 1979	Aug/20 1979	Jan/15 1980	Cleanup No. 5	51,010	40,430	-4.0 -4.5	0.5	Silt	Offshore discharge with box barge	350	17.1	60.0	Cleanup No. 5; transportation with box barge; disposal area
36	The Tokyo Metropolis	Dredging of dirty soils at Shinshiba, Shinshibaura, Kita Shibaura & Nishi Canals for 1979	Jan/17 1980	Apr/20 1980	Cleanup No. 5	11,640	18,235	-2 -3.2	0.7 1.2	Silt	Offshore discharge with box barge	300	21.7	65.0	Cleanup No. 5; transportation with box barge; disposal area
37	Niigata Pref.	Toyanogata River purification work	Feb/24 1979 Feb/7 1980 Mar/21 1980	Mar/13 1979 Mar/5 1980 Apr/6 1980	Cleanup No. 1	39,440	7,500	-1.7	0.5	Silt	500 2,000	56	69.6	39	Cleanup No. 1; booster pump; sedimentation area; transportation with discharge pipe; transportation with discharge pipe

(Continued)

Table 2 (Concluded)

No.	Client	Description of Works	Contract Period From	Contract Period Until	Dredge Employed	Specifications for Dredging Work: Area (m^2)	Specifications for Dredging Work: Volume (m^3)	Specifications for Dredging Work: Soil Depth (m)	Specifications for Dredging Work: Discharge Thickness (m)	Specifications for Dredging Work: Characteristics	Specifications for Dredging Work: Distance (m)	Efficiency: Pumping Volume (m^3/hr)	Efficiency: Density (%)	Efficiency: Dredged Volume (m^3/hr)	Ooze Treatment
38	The Tokyo Metropolis	Dredging of dirty soils at Takahama/ Shibaura-Nishi Canal	Jun/12 1980	Mar/31 1981	Cleanup No. 5	64,266	44,986	-2.7 -3.0	0.7	Silt	130	300	31.2	95	Cleanup No. 5; box barge; disposal area
39	Port Construction Div. 3	Investigation for dredging work at Osaka Bay	Aug/4 1980	Oct/15 1980	Cleanup No. 3	4,800	3,840	-13.5 -14.6	0.4 1.2	Silt	Unloading with box barge	285	75.8	216	Cleanup No. 3; transportation with box barge; unloading with barge unloader
40	Miyagi Pref.	Sludge dredging & removing for improvement of fishery environment at Kesennuma Bay for 1980	Aug/15 1980	Oct/31 1980	Cleanup No. 3	27,600	13,800	-4.0 -7.0	0.5	Organic dirty soils	Offshore disposal with sand carrier with grab bucket	3[illegible]	60.0	210	Cleanup No. 3; sand carrier with grab bucket; offshore disposal
41	Okayama Pref.	Dredging of basin at Yobimatsu Channel	Feb/23 1981	Mar/26 1981	Cleanup No. 2	57,750	23,100	-4.0	0.4	Silt	250	800	25.0	200	Cleanup No. 2; box barge; unloading with barge unloader
42	Mitsubishi chemical industries & other private companies	Maintenance dredging at Yobimatsu Port & other works	May/9 1981	Sep/10 1981	Cleanup No. 2	76,800	79,070	-4.5 -17.0	0.45 1.80	Silt with coarse sand	250	800	13.8	110	Cleanup No. 2; box barge; unloading with barge unloader

Table 3. Results of Investigation abut the Generation Unit of Turbidity

Dredge	Location	Dredged Volume (m^3/hr)	Investigated Results			Cutting of Soil per Swing(m)	Soil Characteristics		Dredging Conditions		Generation Unit of Turbidity	
			Swing Speed(m/min)	Swing Width(m)	Advance Distance(m)*		Silty and Finer Materials	Clay and Finer Materials	Tidal Speed(m/sec)	Water Depth(m)	Generation Unit in Investigated	Standard Generation Unit**
CLEAN UP No. 1	B Harbor	45	3- 3.7	30	1 - 1.5	0.3			0.2	3.75	0.00518	
CLEAN UP No. 2	Y Harbor	137.3	3.5	52	3	0.44	98	57	0.02	8	0.000397	0.000442

* Advance distance means the moving distance of speed with one swing.
** Standard generation unit of turbidity is the generation unit under the condition of tidal current speed U = 7 cm/sec.

PERFORMANCE TESTS OF PNEUMA DREDGE PUMP

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ABSTRACT

Results of pumping performance and turbidity generation tests of the air-operated PNEUMA dredge pump, model 600/100, are summarized. Tests were conducted at four locations in sand and fine-grained sediments and in different water depths. The following are described: (a) test locations and characteristics, (b) data acquisition methods, (c) pumping performance results, (d) variations in performance with sediment type and water depth, (e) noteworthy characteristics of PNEUMA pump operation, and (f) results of turbidity monitoring. Conclusions are given regarding pumping capabilities and recommendations made for potential improvements.

INTRODUCTION

In the period 15 August - 5 October 1978, the U. S. Army Corps of Engineers conducted tests of a compressed-air-powered, solids-handling pump called the model 600/100 PNEUMA pump. The purpose of these tests was to evaluate: (a) pumping performance, (b) turbidity generation, and (c) usefulness of the pump in a number of typical maintenance dredging situations. Items (a) and (b) were the responsibility of the U. S. Army Engineer Waterways Experiment Station (WES). Item (c) was analyzed by the U. S. Army Engineer District, Wilmington (SAW). The purpose of this paper is to present primarily a summary of items (a) and (b), together with several observations on item (c).

PNEUMA PUMP

The model 600/100 PNEUMA pump includes several major components. The pump body (Figure 1) consists of three large cylindrical pressure vessels, each with a material intake on the bottom and an air port and discharge outlet on top. Check valves limit flow through the intakes and outlets to one direction only, but air can flow in both directions through the air port. The three discharge outlets join in a single discharge pipe directly above the pump body. Attachments may be fitted to the material intakes for dredging different types of sediments. The model 600/100 pump body is approximately 4.4 m high by 3.7 m wide and weighs 6700 kg. Each pressure vessel is 2.0 m high and 1.5 m in diameter and has a usable volume of approximately 2800 litres.

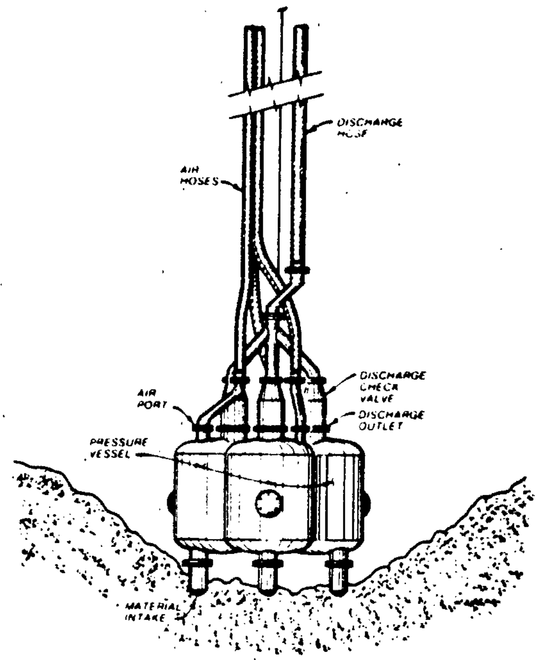


Figure 1. PNEUMA pump body

The operating cycle of a single pressure vessel is illustrated in Figure 2. When dredging, the material intake is buried in the bottom. Venting the air port to atmospheric pressure causes flow into the material intake due to ambient water pressure. This flow continues until the pressure vessel is nearly full, at which time compressed air is forced into the vessel through the air port. The compressed air forces material out of the pressure vessel through the discharge outlet. When the vessel is nearly empty, the air port is vented to atmospheric pressure and the operating cycle begins again. The pump body consists of three pressure vessels, so their operating cycles are timed to be out of phase with each other but overlap sufficiently to minimize discharge surging. An important aspect of the PNEUMA pump's operating principle is that it depends on ambient water pressure as an excavation force. Therefore, it should excavate more efficiently in deep water than shallow water.

The timing and speed of the operating cycles are controlled by an electrically driven, variable speed air distributor (Figure 3), located on the surface. The air distributor is connected to the model 600/100 pump body by three 100-mm flexible hoses, each leading to a pressure vessel air port. A single 250-mm flexible hose carries discharge from the pump body back to the surface, where it connects to the discharge pipeline. The pump body and hoses are usually suspended from a crane or other lifting device for dredging, although other types of support are possible.

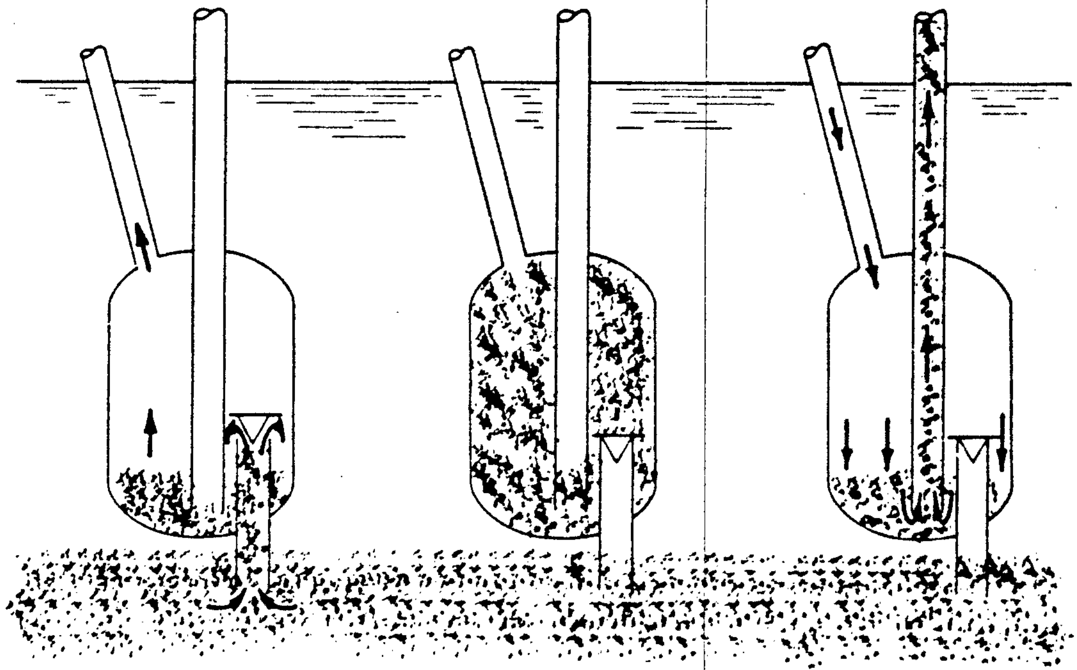


Figure 2. PNEUMA pressure vessel operating cycle

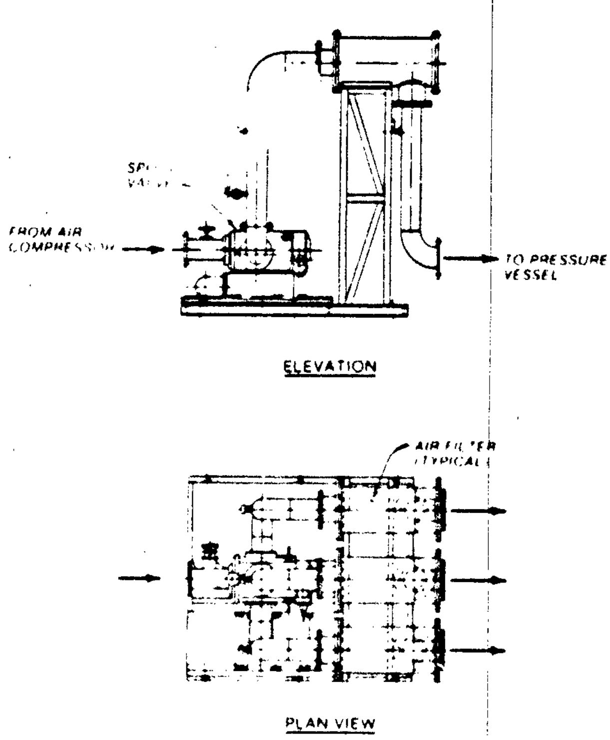


Figure 3. PNEUMA air distributor

TEST PROGRAM

The model 600/100 was tested at four locations: a river channel, a lock approach, a tidal inlet, and a dock area in an estuary. The characteristics of each location are summarized in Table 1 and Figures 4-7. The test configuration of the PNEUMA pump and supporting equipment is shown in Figure 8. At the river channel test site, only water was pumped. Therefore, the discharge was placed directly back into the river. At the lock approach and dock sites, the discharge was pumped into a hopper barge for disposal at other locations. At the tidal inlet, material was pumped through a 250-mm-diameter steel pipeline of varying length.

TABLE 1. PNEUMA PUMP TEST SITE CHARACTERISTICS

Test Site Location	Water Depth (m)	Sediment Type	Sediment d_{50} (mm)	In Situ Sediment Specific Gravity	Pumping Distance (m)	Test Period (days)
River Channel	3.0-9.1	Water	--	--	35	10
Lock Approach	1.8-3.4	Sand	0.6	2.11	35	8
Tidal Inlet	3.0-4.6	Sand	0.4	2.01	128-610*	11
Dock	3.7-10.7	Silt/Clay	0.008	1.09** 1.53	35	16

* Pipeline length was changed several times during testing.
** Varied with location and depth in sediment.

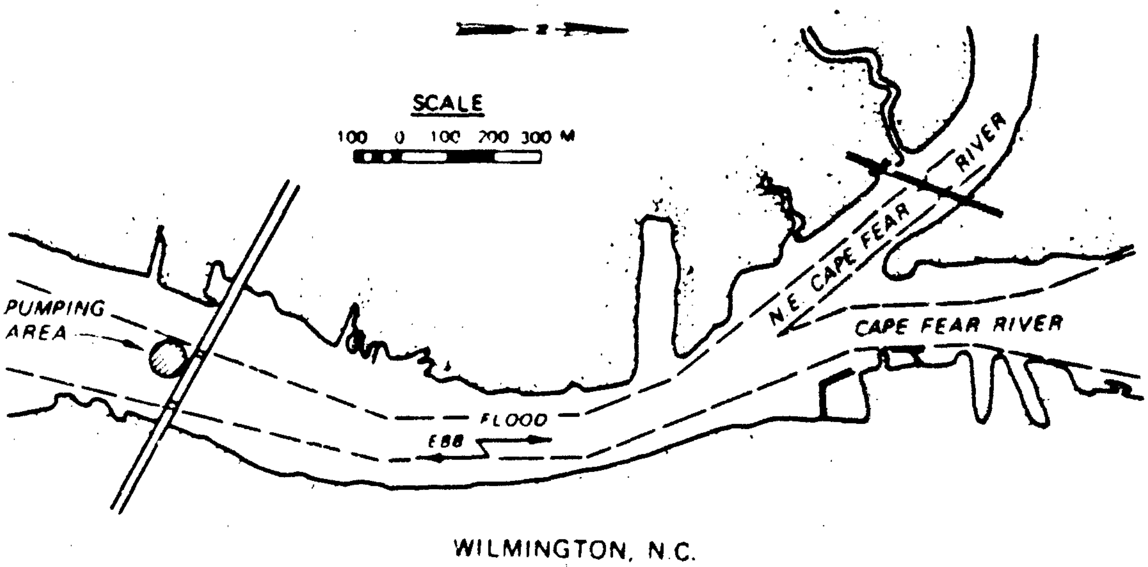


Figure 4. River channel test site

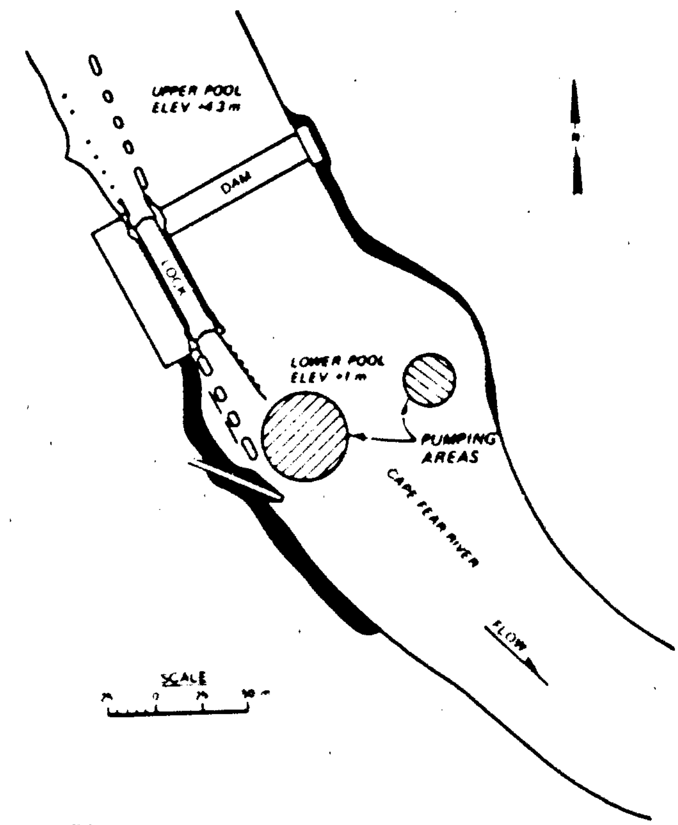


Figure 5. Lock approach test site

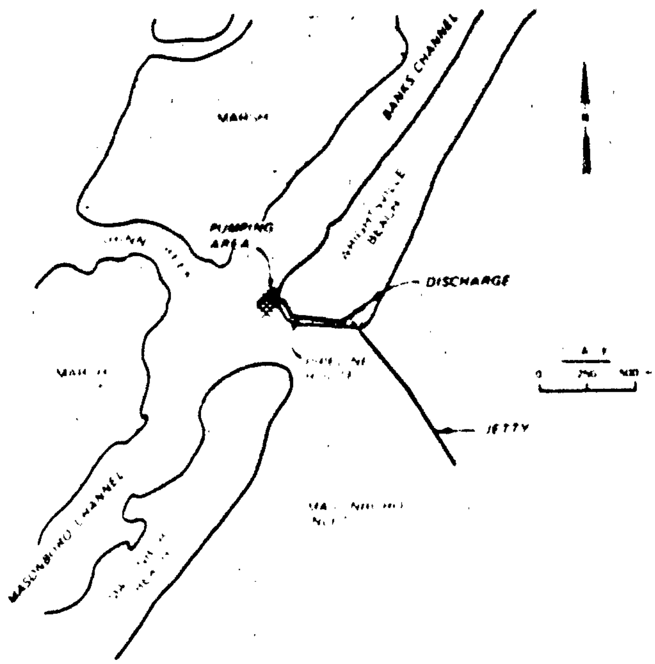


Figure 6. Tidal inlet test site

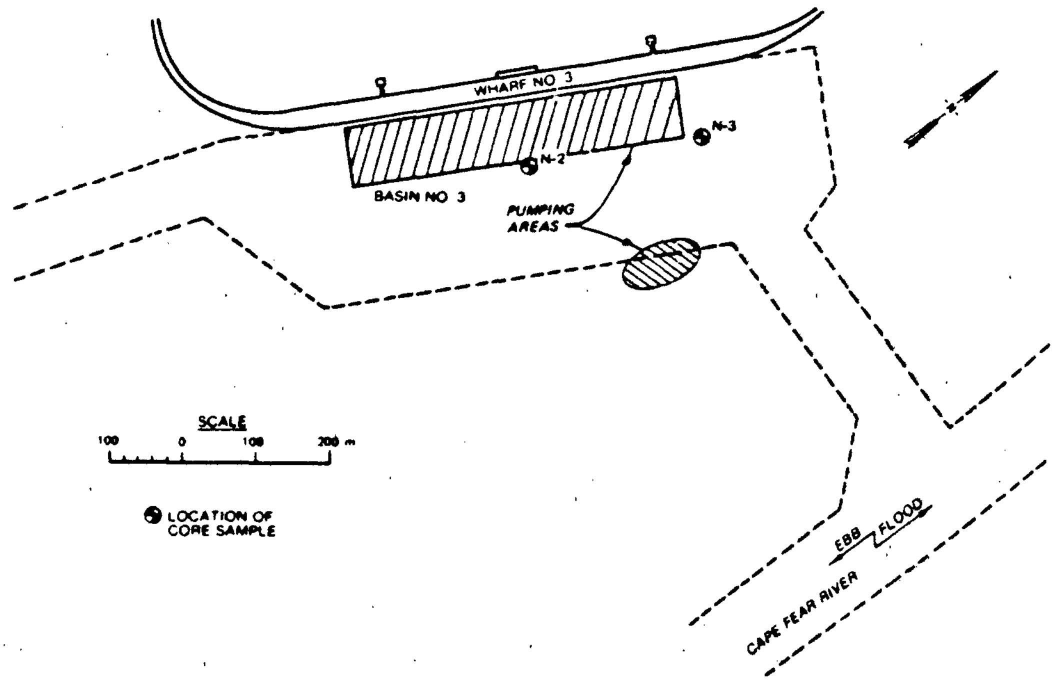


Figure 7. Dock test site

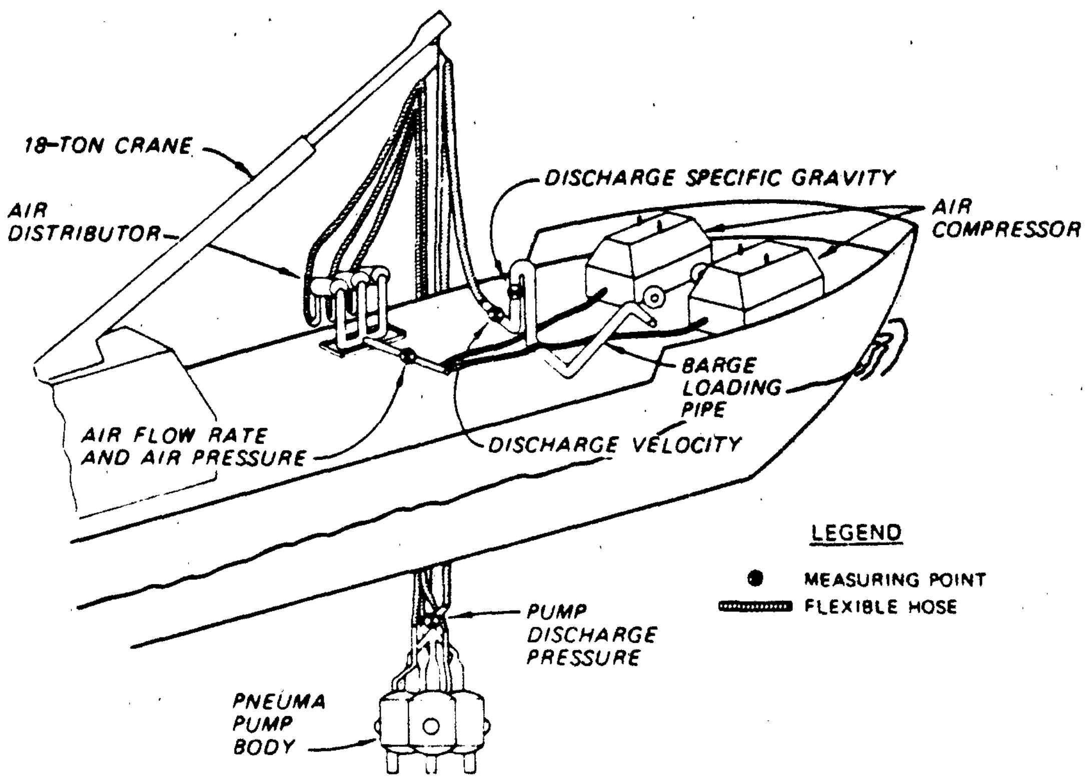


Figure 8. PNEUMA test configuration

A considerable amount of support equipment was needed to conduct tests of the PNEUMA pump. A 32-m-long vessel was used to carry the pump body, air distributor, hoses, accessories, instruments, and air compressors. An 18-ton hydraulic crane on the vessel lowered the pump body to the bottom and raised it back to the vessel's deck. A 44-m-long self-propelled hopper barge with a hopper capacity of 241 cu m was needed at two sites to receive pump discharge. Air to power the PNEUMA pump was provided by two compressors, each capable of supplying 29.7 standard cubic meters per minute of air at 6.89 bars pressure. Part of the compressors' output was vented to the atmosphere through a bypass valve prior to reaching the air distributor. The PNEUMA pump operator varied the bypass valve opening as a crude method of regulating airflow into the air distributor.

As shown in Figure 8, several instruments were used to measure and record parameters describing pump performance. Air flow velocity, temperature, and pressure were measured by an instrument which converted these values to a standard volumetric flow rate. The PNEUMA pump discharge pressure was measured by a transducer located just above the pump body where the discharge outlets join. Discharge velocity was measured by an ultrasonic doppler velocity meter, and discharge specific gravity was monitored by a nuclear density meter. Values of airflow rate, air pressure, pump discharge pressure, discharge velocity, and discharge specific gravity were recorded at 10-second intervals on a multi-channel strip chart recorder. Continuous recordings were also made of two of the measured parameters, usually discharge specific gravity and either pump discharge pressure or discharge velocity.

TEST RESULTS

More than 51 hours of pumping data and 4 hours of turbidity measurements were collected during the PNEUMA tests. The pumping tests were conducted in a series of 61 test runs, each run lasting from 20 to 70 minutes, with a typical run averaging 45 to 50 minutes. Data from the runs were compiled in three ways: (a) plots of airflow rate, discharge velocity, and discharge specific gravity for each run; (b) histograms of discharge percent solids and in situ excavation rate for selected portions of certain runs when the pump was performing well; and (c) tables of interpolated synoptic data on airflow rate, air pressure, discharge velocity, discharge flow rate, discharge specific gravity, discharge percent solids, in situ excavation rate, discharge pressure, total discharge head, pump input power, pump output power, and pump efficiency. For discussion purposes, pump performance data are grouped according to whether the pump was discharging water, sand, or fine-grained sediment (silt/clay). The results of turbidity measurements are treated separately.

Water Tests

Three test runs were made in a river channel with the PNEUMA pump discharging clear water. During each run, a valve on the discharge pipeline was closed in a series of steps to produce increased discharge resistance. Water depth over the pump was also varied from 3.0 to 9.1 m. Figure 9 shows the airflow rate and discharge velocity for one test run made at a constant water depth of 6.0 m. The effects on discharge velocity of closing the discharge pipeline valve are seen in the period from 15 to 30 minutes. With the valve fully open, discharge velocities were approximately 4.2 m/s. Closing the valve in steps to approximately three-fourths closed caused velocities to drop to

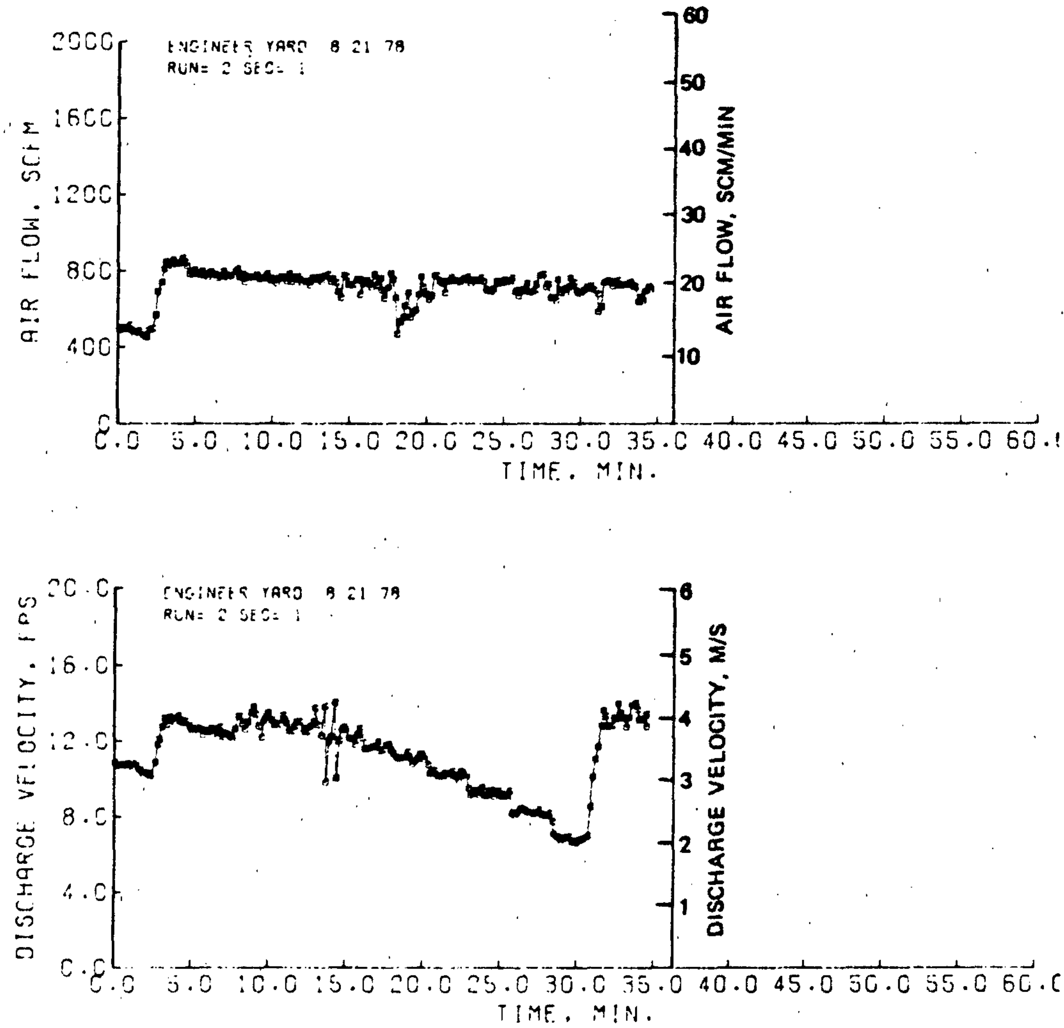


Figure 9. Example airflow rate and discharge velocity, water tests

approximately 2.1 m/s. During the entire run, the airflow rate remained roughly constant at 21 to 22 standard cubic metres per minute. Efficiency of the PNEUMA pump during the water tests, expressed as the ratio of pump output power to pump input power, was usually in the range of 8 to 12 percent.

Data taken during the water tests indicated that the airflow rate required by the PNEUMA pump for a given discharge varied directly with the depth of water over the pump. This should be expected, since the PNEUMA pump operates on the positive-displacement principle using a compressible "piston" (air). Since airflow rate is roughly equivalent to power, this means that power required by the PNEUMA pump varies directly with depth for a given pump output. For a centrifugal or conventional piston pump, depth variations have only secondary effects on power consumption.

Sand Tests

Sand was pumped at two test sites - the lock approach and the tidal inlet. The lock approach sand was coarser and water depths were less, but the pumping distance there was several times shorter (see Table 1). Because of the shallow water depths at the lock approach, the PNEUMA pump experienced some difficulty in excavating sand there. This also limited the airflow rate which could be supplied to the pump and, consequently, discharge velocities at the lock approach were relatively low. However, most phenomena related to operation of the pump were similar at both sites and can be discussed together. A summary of the more important phenomena noted during the sand tests is as follows:

a. The pump discharge specific gravity was usually considerably less than the in situ sediment specific gravity. Figure 10 shows a composite histogram of pump discharge percent solids and corresponding values of specific gravity which represent the periods of best performance in sand. The predominant range of discharge percent solids by volume is 10 to 25 percent, corresponding to specific gravities of 1.17 to 1.41.

b. The pump discharge showed significant, systematic variations in specific gravity and velocity which can be related to the way in which a PNEUMA pump operates. Figure 11 shows part of a continuous record of discharge specific gravity made during a test run at the tidal inlet. A repeating variation with a period of 33.5 seconds is evident, corresponding to the time required for the air distributor to make one cycle through all three pressure vessels. Within a single cycle, three distinct peaks appear, each representing the discharge of a single pressure vessel. At the same time, discharge velocity usually varied in a similar manner. Figure 12 shows a continuous record of discharge velocity taken when the air distributor was run at a slower speed with a cycle time of 45.5 seconds. Again, the variations due to each pressure vessel are evident.

c. Pump discharge velocity was observed to vary inversely with discharge specific gravity, especially at lower airflow rates. Figure 13 shows this relationship, and also shows that the velocity dropped to near zero when discharge specific gravity approached an in situ sediment value at 13.0 minutes. The velocity/specific gravity relationship was also observed at higher airflow rates, although the variations were less pronounced.

Fine-Grained Sediment Tests

Tests pumping fine-grained sediment were conducted at one location, a dock area, in water depths deeper than for the sand tests. The sediment pumped was relatively unconsolidated and easy to excavate. However, unlike sand it would not flow to the pump by gravity when an excavation was begun. Therefore, the pump had to be moved continuously by the boat while pumping to obtain a constant source of sediment. Results of the fine-grained sediment tests are summarized as follows:

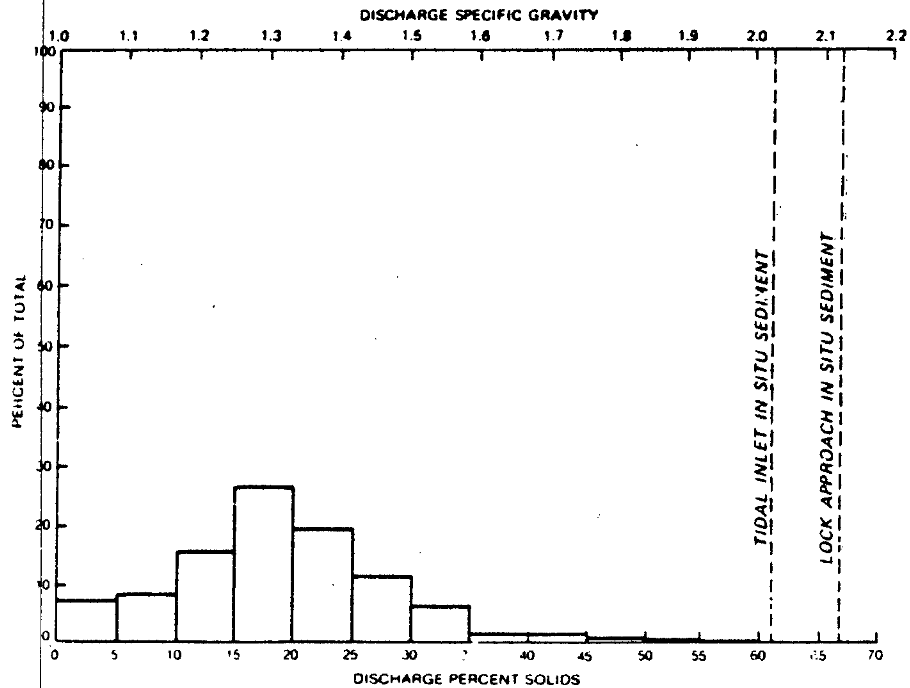


Figure 10. Composite histogram, discharge percent solids and specific gravity, sand tests

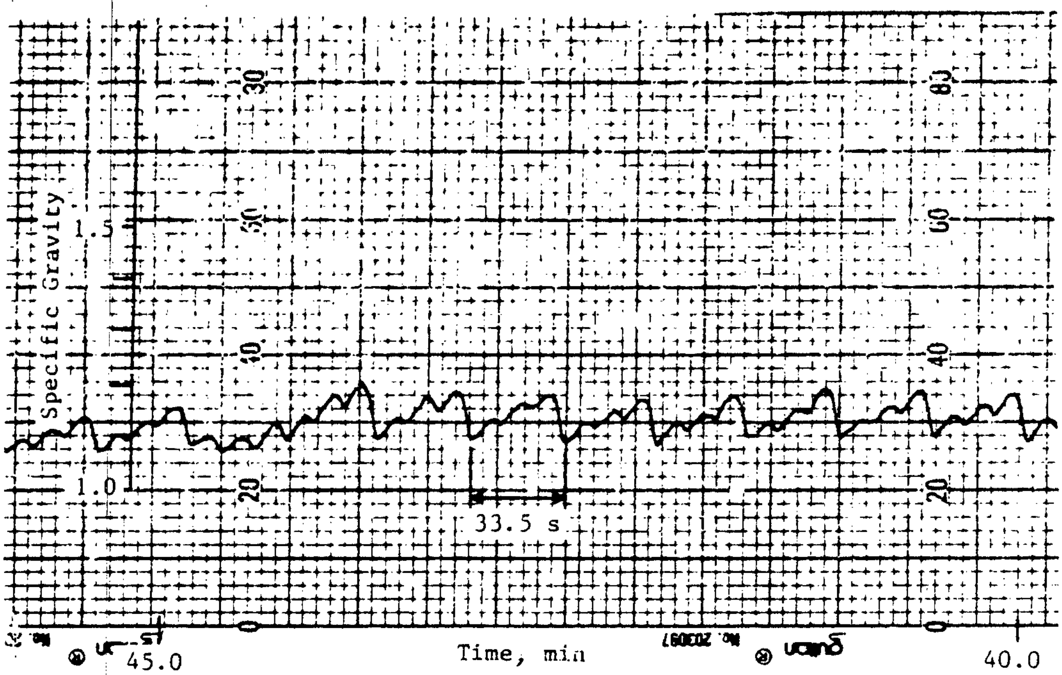


Figure 11. Example discharge specific gravity, sand tests

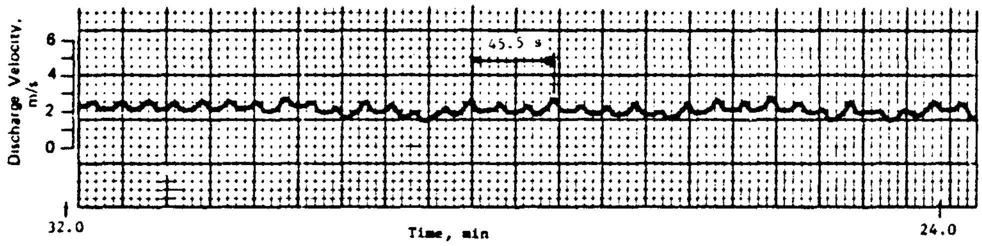


Figure 12. Example discharge velocity, sand tests

a. Pump discharge specific gravity was usually within the range of measured in situ sediment values when the pump was operating well. Figure 14 is a composite histogram representing periods of good pump performance.

b. Most phenomena related to pump operation were similar in nature but of less amplitude than in the sand tests. Discharge specific gravity variations appeared to be connected more to problems in obtaining a constant sediment supply for the pump than to the way in which the pump operates. When pumping well, the discharge specific gravity at times was almost constant (Figure 15).

c. The PNEUMA pump was able to produce a more constant discharge specific gravity in fine-grained sediment than in sand. However, the method used for deploying the pump in fine-grained sediment made it difficult to continue pumping sediment for periods longer than 10 or 11 minutes. In pulling the pump along the bottom, the material intakes may have changed position often and the pump may have moved in and out of sediment layers.

Turbidity Generation Tests

Water samples were collected at 10-minute intervals and four water depths during three PNEUMA pump test runs in fine-grained sediment. Samples were taken adjacent to the pump and downstream at various distances to measure both turbidity generated at the pump and the extent of any turbidity plume. Before each run, samples were taken to determine the levels of naturally occurring turbidity. Each sample was analyzed for suspended solids in milligrams per litre and for turbidity in Nephelometric Turbidity Units.

Results of the turbidity generation tests were somewhat inconclusive. There was evidence of some turbidity generation by the pump, especially in the lower water column, but the turbidity was generally short lived. Figure 16 shows the time history of suspended sediment values for one run for samples taken downstream of the pump. During this run, the PNEUMA pump discharged an in situ density slurry for four time intervals totaling approximately 12 minutes. This discharge correlated roughly with the increases in suspended sediment seen in the latter part of the test run in Figure 16. Other test runs produced similar results; however, in all cases the periods of high density discharge were too short to determine what the fully developed turbidity levels might be after sustained pumping. The levels measured did not represent excessive increases over naturally occurring values.

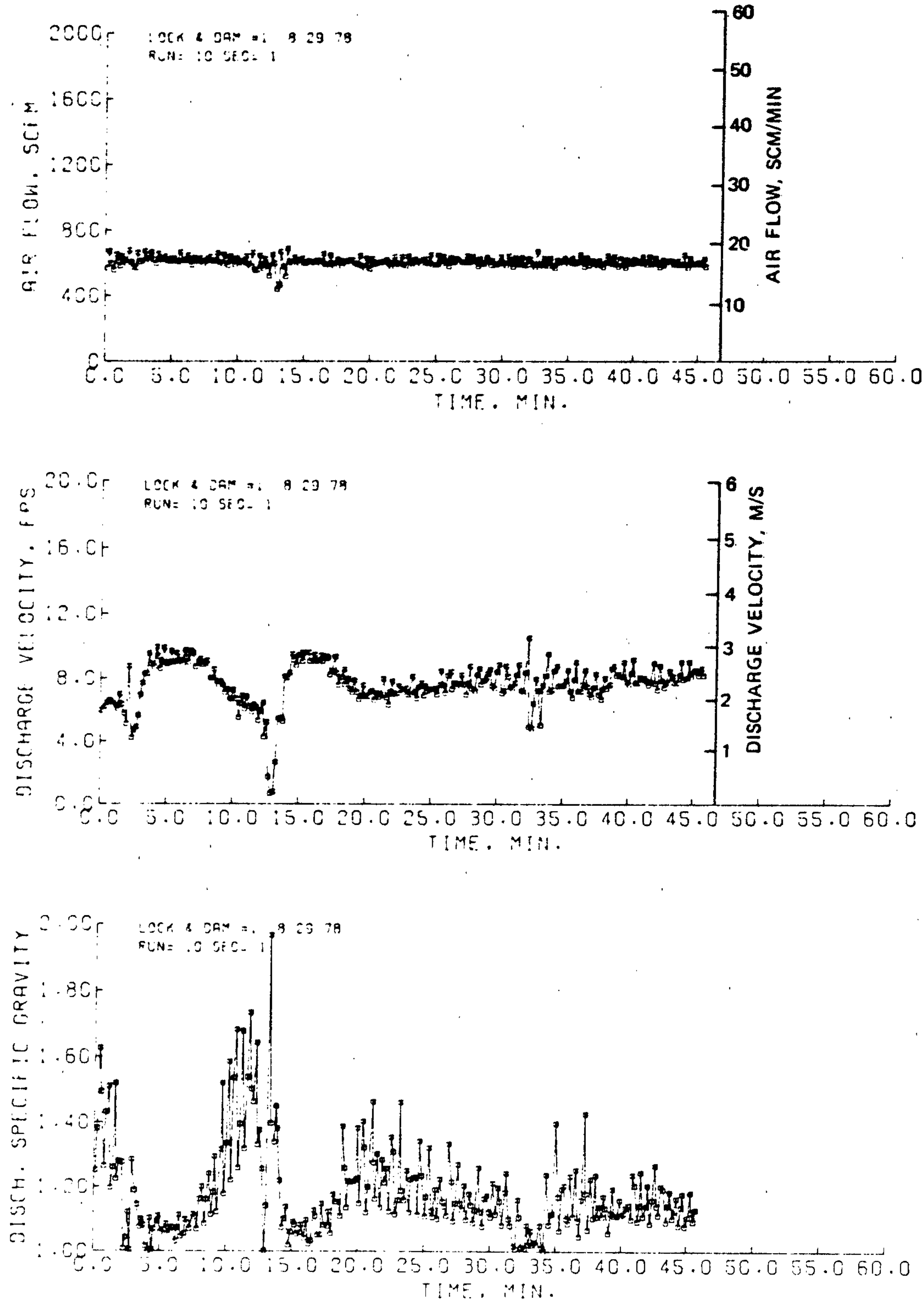


Figure 13. Example airflow rate, discharge velocity, and discharge specific gravity, sand tests

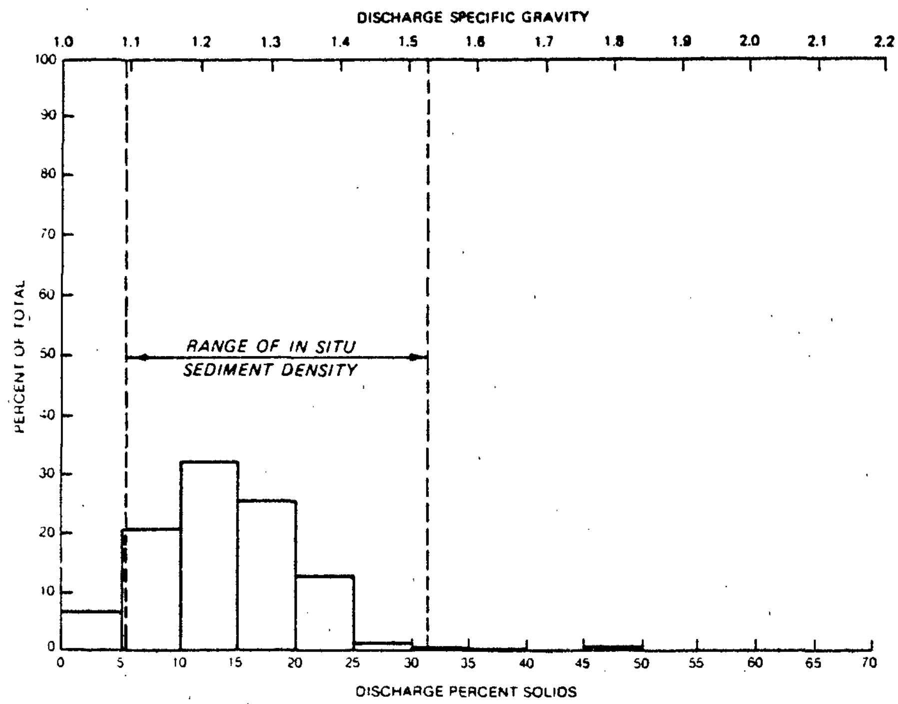


Figure 14. Composite histogram, discharge percent solids and specific gravity, fine-grained sediment tests

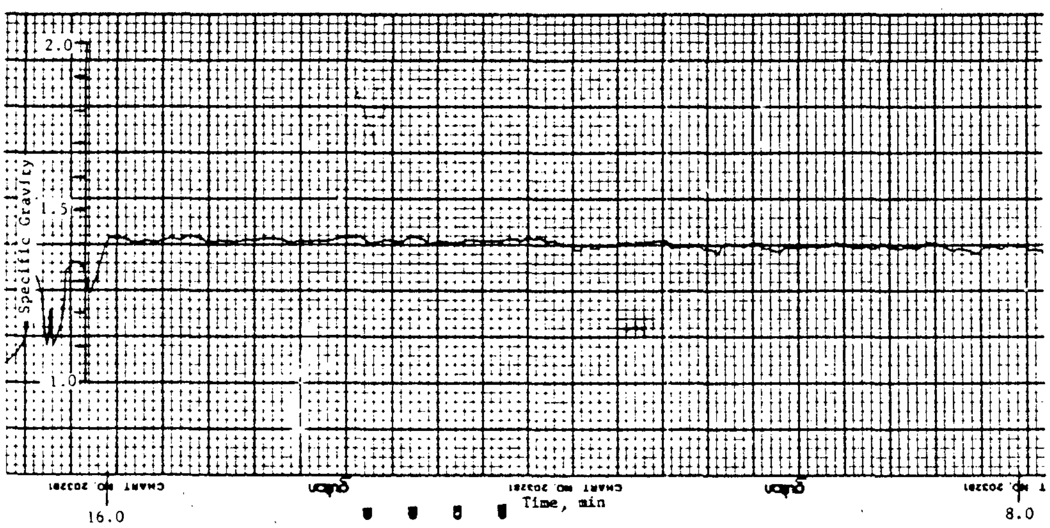


Figure 15. Example discharge specific gravity, fine-grained sediment tests

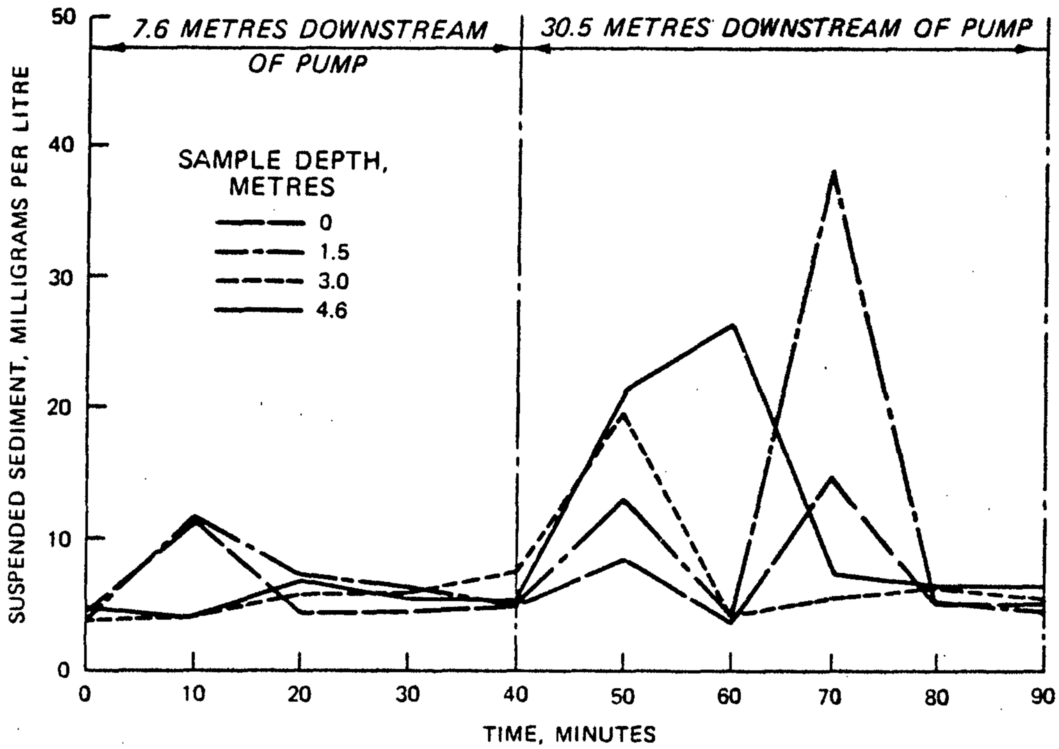


Figure 16. Example suspended sediment values downstream of PNEUMA pump

CONCLUSIONS AND RECOMMENDATIONS

The following general conclusions were drawn from tests described in this paper:

a. The PNEUMA pump could remove fine-grained sediment from the bottom at an in situ density but could not achieve the same results in sand.

b. High density discharge could be sustained only for short periods, usually 15 minutes or less. This was caused in part by difficulty in deploying the pump properly and in part by shallow water depths and compacted sand making excavation difficult. It was observed that the pump could excavate sand only in water depths greater than 2.5 m.

c. The PNEUMA pump has a low power efficiency compared with a centrifugal dredge pump. Calculated efficiencies pumping water, sand, or fine-grained sediment were always less than 20 percent and often less than 10 percent.

d. The PNEUMA pump appeared to generate some turbidity when dredging fine-grained sediment, but the relative increases measured were not excessive and could only be loosely correlated to pump operation. It is possible that a better method of deploying the pump than that used in these tests would lower turbidity levels even further.

Some areas for potential improvement of the PNEUMA pump are suggested as a result of these tests:

a. Reduce pump size and weight to make handling easier.

b. Replace mechanical air distributor with valve system on pump body. This would eliminate two air hoses and possibly reduce air energy losses.

c. Add vacuum system to pressure vessels to improve shallow water performance.

d. Improve pump efficiency by reducing energy losses within each pressure vessel. One way of doing this would be to improve the system of check valves and pipe inlets which handle flow within each vessel.

e. Develop better methods for deploying the PNEUMA pump, using more rigid, controllable support systems built specifically for the pump.

ACKNOWLEDGEMENTS

The investigations described were accomplished using funds provided by the Office, Chief of Engineers, U. S. Army. Permission was granted by the Chief of Engineers to publish this information. The author wishes to acknowledge the contributions of the following persons in collecting and analyzing the test data: Mr. J. E. Hite, Jr., Mr. R. A. Shafer, Mr. J. D. Ethridge, Jr., Mr. J. D. Tarver, Mr. E. W. Flowers, Mr. S. E. Varnell, and Mr. W. C. Strahan, Jr. The author also thanks Mr. W. H. Sanderson, Mr. D. M. Howard, and other personnel of the Wilmington District for their support during the test program.

SEDIMENT RESUSPENSION IN THE VICINITY OF THE CUTTER HEAD

Hiromi Koba
Toyoaki Shiba

INTRODUCTION

Dredging work in Japan has been conducted, in most cases, by cutter suction dredges. This method has a greater dredging efficiency as well as a wider range of application to cope with the conditions of execution relating to soil, water depth, discharging distance, etc. At the same time, it is known that when the bottom material is dredged by a cutter, the fine-grained dredged material is suspended, thus causing sediment resuspension in the vicinity of the cutter head during the dredging operation.

In Japan, many marine products have been used for food since ancient times. In recent years, culture fishermen of sea breams, young yellowtails, oysters, lavers, etc., have become quite active in the sea off the coast, thanks to the progress in culture technology.

It is feared that resuspension from dredging work conducted in the sea adjacent to culture farms will adversely affect fish and larva. Hence, the period of dredging work is often restricted and other dredging methods causing less sediment resuspension are often adopted instead.

In order to continue using the efficient cutter suction dredge while coping with the resuspension situation, it is first necessary to understand sediment resuspension in the vicinity of a cutter head. We decided to study sediment resuspension and work out measures to prevent it by conducting an indoor modeling test of the cutter.

DREDGING OPERATION

The usual method of a cutter suction operation is to fix its stern by a spud and let the end of a dredge ladder extend from its bow into the seabed. The bottom material is then dredged by revolving the cutter attached to the end and pumping the material up with the water.

Various shapes of cutters are used according to the nature of the soil. The standard cutter (Figure 1) has blades virtually parallel with a cutter shaft and a suction mouth installed behind the blades.

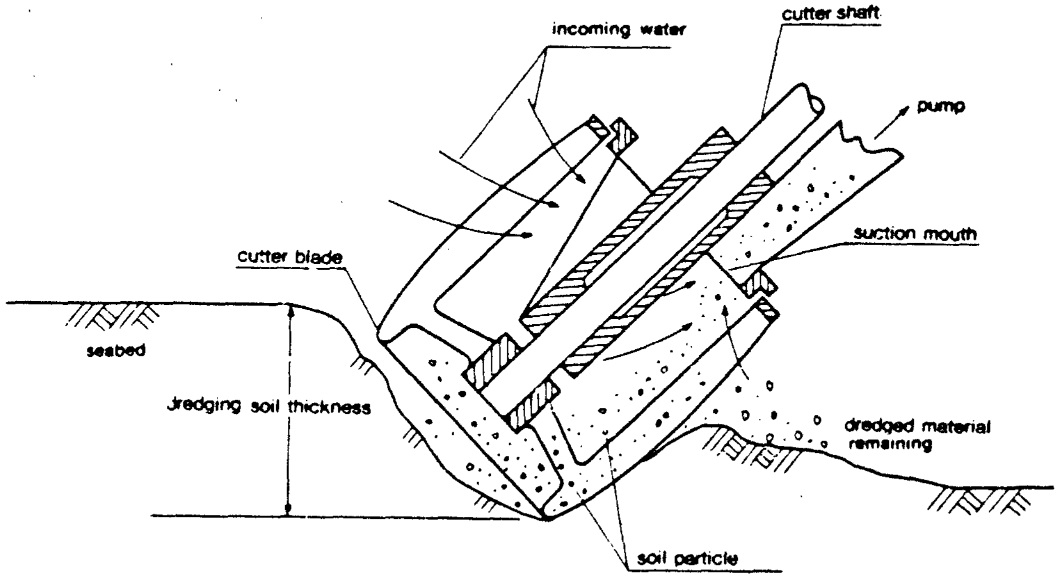
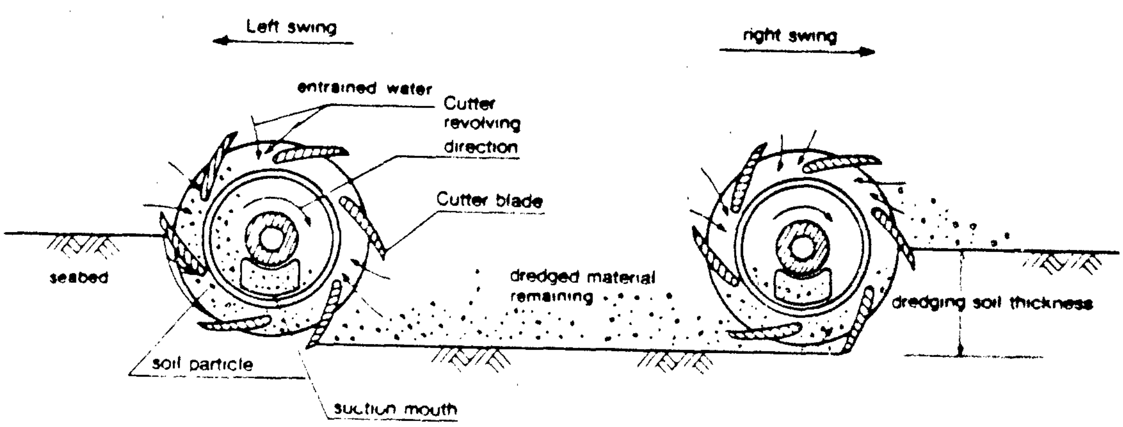


Figure 1. Cutting operation (side view)

The bottom material scarified by cutter blades moves toward the suction mouth with the water entrained pulled in by the dredging pump and the screw operation of the blades themselves. Some material is left in the dredging track behind the cutter. The direction of the cutter revolution is fixed clockwise regardless of its swing direction. The cutting operation of the bottom material varies according to the direction of swing as shown by Figure 2.



UNDER CUTTING

OVER CUTTING

Figure 2. Cutting operation (front view)

Figure 2 shows the condition of the cutter seen from the side of a dredge. In the left swing direction, cutter blades cut up the bottom material from beneath; this is called "under cutting." In the right swing direction it is called "over cutting." As is clear from Figure 2, dredged material is easily supplied to the suction mouth in the under cutting since the blades scoop up the dredged material from below. In the over cutting, however, the blades cut the bottom material from above and splash the dredged material under the cutter and opposite the swing direction, thus making it difficult to deliver the dredged material to the suction mouth. Therefore, under cutting has a higher concentration of dredged material than over cutting and the amount of material left behind is smaller. Concentration in this case means the percentage the bottom material dredged from the seabed occupies in the mixture sucked by a dredging pump. This concentration is also used as an indicator of dredging efficiency.

When an operator engaged in the dredging work wants to increase the dredging efficiency, he generally manipulates levers to increase the amount of dredged material by increasing the swing speed and the dredging soil thickness. The cutting operation, as mentioned above, varies considerably according to the swing direction. Hence, a study was conducted on the effect of swing direction on sediment resuspension during dredging.

Judging from Figures 1 and 2, sediment resuspension results in the vicinity of the cutter head as fine particles of the dredged material are left behind floating and suspended. It is believed that increased dredging soil thickness and swing speed as well as use of the right swing direction cause sediment resuspension. If the cutter revolution is increased, the centrifugal force on dredged material and water flow in the vicinity becomes greater, thus presumably increasing the amount of the sediment resuspension. Thus viewed, the operation designed to increase the dredging efficiency generally increases the sediment resuspension in the vicinity of the cutter head.

EXPERIMENT TO DECREASE SEDIMENT RESUSPENSION

Factors causing sediment resuspension by a cutter suction dredge include natural conditions relating to the soil and tides as well as the operating conditions relating to the speed of cutter revolution, swing speed, and shape of a cutter, etc. Of these factors, measures most likely to decrease sediment resuspension are those concerned with the operating conditions. By experience, it is thought that the following steps should be taken to decrease resuspension:

a. Slow down cutter revolution.

b. Slow down swing speed.

c. Start dredging from the ground surface and decrease the soil thickness to be dredged by a cutter at a time.

d. Increase the amount of water to be pumped.

The operations mentioned above are effective in decreasing sediment resuspension, but they also tend to decrease the dredging efficiency. In order to minimize the sediment resuspension without greatly lowering the

dredging efficiency, it is necessary to prevent the sediment resuspension without greatly changing the existing dredging mechanism. There are many factors causing the sediment resuspension in the vicinity of the cutter head, but the biggest factor is believed to be the scattering of the dredged material by the centrifugal force of the cutter. Therefore, it was thought that a cover around the cutter may help decrease the sediment resuspension in the vicinity of the cutter head. A modeling test was conducted to ascertain the effect of the cover. The basic design of the cover was such as to enclose the cutter. However, a study was also made of a side cover in the swing direction which could be closed and opened. A front cover that may obstruct the flow of the dredged material was designed to be removable.

MODEL TEST

Basic Policy of Experiment

The experiment of a model, unlike that of a prototype, is subject to various restrictions. In this regard, a basic policy was adopted to conduct a study on the following three points:

a. The mechanism causing the sediment resuspension in the vicinity of the cutter head.

b. The effect of preventing the sediment resuspension by the cutter cover.

c. The effect of a cutter cover on the dredging efficiency.

Test Methods

In the experiment a 4,000-p.s. pump dredge was used as a prototype and the Froude model rule was applied at a scale of 1 to 25. The operation conditions of the prototype and the model are shown in Table 1.

Table 1. Operating Conditions of Prototype and Model

Item	Prototype	Model
Pumping	5000 m^3/hr	27 ℓ/min
Swing Speed	10 m/min	60-200 cm/min
Cutter revolution	20 rpm	100 rpm
Dredging soil thickness	1-3 m	6 cm

The model experiments were conducted with various operating conditions fixed except for swing speed. The experiments were also carried out on three different kinds of models: a standard type cutter model, a model

equipped with a cover as shown by Figure 3, and a model whose front cover was removed.

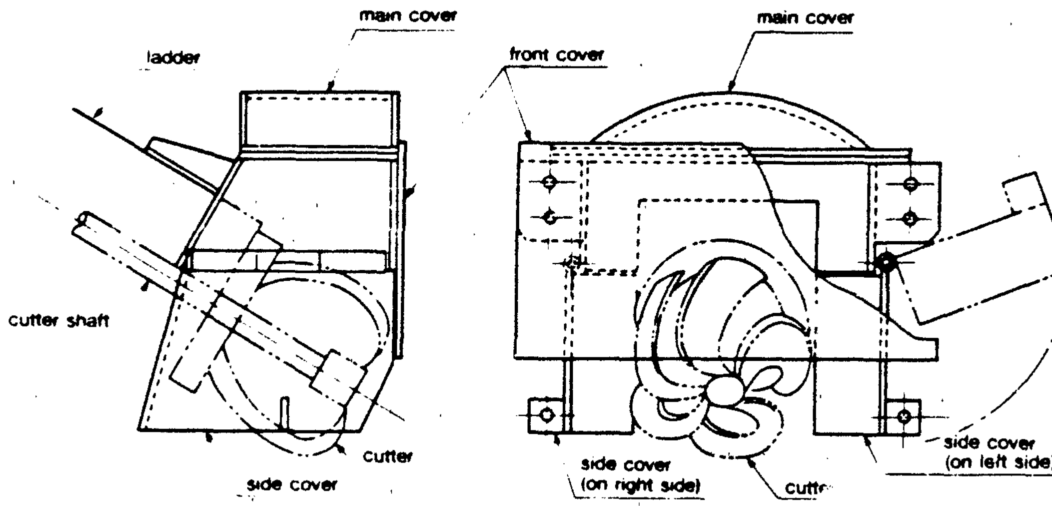


Figure 3. Cutter cover model

Test Results

The test results are shown in Figure 4 for sediment resuspension and in Figure 5 for dredging efficiency.

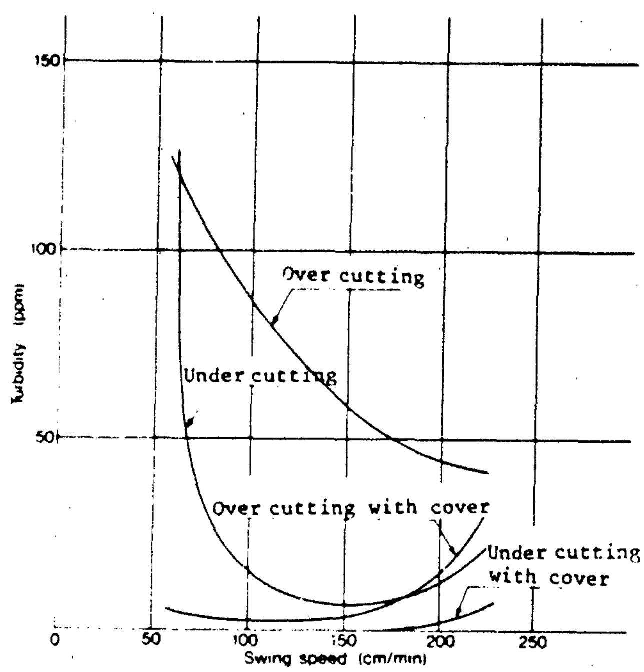


Figure 4. Sediment resuspension

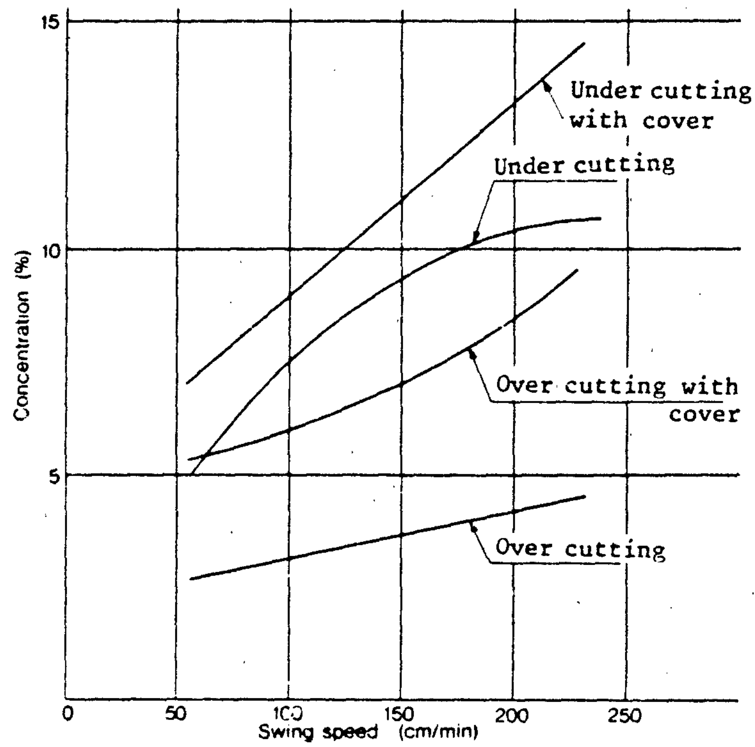


Figure 5. Dredging efficiency

It may be problematical to draw a quantitative conclusion on the basis of the test conducted alone; however, we believe a considerable trend concerning sediment resuspension and dredging efficiency could be detected. The following are some of the salient points of the result of the modeling test:

a. Sediment resuspension in the vicinity of the cutter head is caused by floating and suspension of the dredged material scattered radially around the cutter mainly due to the cutter's centrifugal force and the dredged material remaining on the track behind the cutter.

b. When there is no cover, the effect of the water flow caused by the revolution of the cutter is great in the area where the swing speed is low and the sediment resuspension increases. This sediment resuspension rapidly decreases in the under cutting mode at a swing speed of 100 cm/min (prototype: 5 m/min); in the over cutting mode it slowly decreases up to a swing speed of 220 cm/min (prototype 11 m/min).

c. When a cover is installed, the sediment resuspension occurring at a swing speed of 180 cm/min (prototype: 9 m/min) is very small.

d. With or without a cover, the sediment resuspension increases when the swing speed is over 180 cm/min (prototype: 9 m/min). This is largely due to the dredged material remaining in the track behind the cutter.

e. When the front cover is removed, the sediment resuspension increases greater than when it is equipped with a front cover when the swing speed is over 180 cm/min (prototype: 9 m/min), but it is still good enough to prevent the sediment resuspension.

f. Dredging efficiency is shown by concentration. In this experiment, the over cutting concentration is about one half that of the under cutting.

g. When the cover is installed, the concentration increases. In over cutting, the concentration becomes twice as much as when there is no cover.

h. When the front cover is removed, the dredging efficiency value stands halfway between the value when there is no cover and when a cover is installed.

As a result of the model testing, it was confirmed that the cutter cover is effective in preventing the sediment resuspension in the vicinity of the cutter head and increasing the dredging efficiency. It was particularly effective when over cutting. It was also confirmed that, even if a front cover is removed, the effect of preventing the sediment resuspension is not much different when there is a cover and the swing speed is below 180 cm/min (prototype: 9 m/min).

CONCLUSIONS

The modeling test was successful in finding out the mechanism causing the sediment resuspension in the vicinity of the cutter head and confirming the effect of preventing the sediment resuspension by a cutter cover.

However, many problems still exist that have to be solved before the cutter cover can be used practically. Further studies are needed on the structure of the cutter cover, operation of dredge, etc., from various angles so that a test can be conducted on an actual dredge in the future.

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THE LONG-TERM EFFECTS OF DREDGING OPERATIONS PROGRAM

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ABSTRACT

In October 1982 the Long-Term Effects of Dredging Operations (LEDO) Program was authorized, funded, and initiated under the sponsorship of the Office, Chief of Engineers (OCE). The stated objectives of LEDO are to provide new or improved state-of-the-art technology for predicting long-term environmental impacts of dredging operations and to improve or develop methods for minimizing any adverse impacts associated with dredged material disposal. The program presently consists of five separate but highly integrated work units in two general work areas: effects of aquatic disposal and effects of upland disposal. LEDO is planned as a continuing program since applied environmental research must address current problems and research priorities are subject to change. The program is managed under the Dredging Operations Technical Support (DOTS) Program at the Waterways Experiment Station (WES). This paper presents the status of the program in its present form and its aims in the near future.

INTRODUCTION

Background

By the early 1970's, concerns over the environmental effects of dredging operations reached the stage where Federal legislation mandated the Corps of Engineers (CE) to undertake a major study to determine the environmental effects of dredged material disposal and to develop procedures for minimizing any adverse effects. To this end, the Dredged Material Research Program (DMRP) was initiated in 1973 and successfully completed in 1978 at a cost of approximately $33 M. The DMRP provided the first definitive information on impacts of dredged material disposal and dispelled many fears expressed at the time. Due to the relatively short time frame of the DMRP (5 years), all questions related to long-term effects of dredged material disposal could not be addressed. Through the Dredging Operation Technical Support (DOTS) Program, established at the completion of the DMRP, low-level monitoring efforts at selected DMRP field sites were undertaken and limited studies have been under way to develop first-generation procedures to evaluate long-term effects.

These efforts have allowed the CE to continue to significantly influence the direction of criteria and guideline development on a national and international level as well as resolve on an interim basis interpretation conflicts with other regulatory agencies. These conflicts, however, have resulted in costly delays on major Federal as well as non-Federal projects.

In early 1980, the CE realized there was a critical need for research on the long-term effects of dredging operations. The Long-Term Effects of Dredging Operations (LEDO) Program is designed to address these critical needs on a continuing basis. The specific work units were identified and developed based on high priority needs submitted by the field (Table 1), close coordination with the field through the DOTS Program, and consultation with EPA and other regulatory agencies. The integrated work units allow specific problems of national concern to be addressed while maintaining the flexibility to address future needs resulting from changing environmental legislation and interpretation of regulations. The work units are grouped into two general work areas:

a. Effects of aquatic disposal.

b. Effects of upland disposal.

The present research program (FY 82) consists of five separate but highly integrated work units in the two general work areas. The work units are planned on a five-year basis; however, it is recognized that applied environmental research must address current problems; consequently, program priorities may change during and after the five-year period. As a result, the program is planned as a continuing program designed to address changing priorities.

TABLE 1. LEDO PROGRAM WORK UNITS

Priority	Work Unit Title
1	Toxic Substances Bioaccumulation and Biomagnification in Aquatic Organisms
2	Environmental Interpretation of Consequences from Bioaccumulation
3	Efficiency of Capping in Reducing Cumulative Effects of Dredged Material Discharge
4	Techniques for Predicting Effluent Quality of Diked Containment Areas
5	Toxic Substances Bioaccumulation in Plants

Program Objective

The principal objectives of LEDO are to provide new or improved technology to predict long-term (including cumulative) environmental impacts of dredging operations and to address methods of minimizing any adverse impacts. The technology will allow the CE to meet its dredging and regulatory missions in a manner that is environmentally sound while reducing or eliminating unneeded environmental constraints imposed on these activities by other regulatory agencies. Such technology is essential in the planning, design, construction, and operation of CE dredging projects as well as in evaluating permitted activities. Study results will provide a valid technical basis for the Corps to continue to influence the direction of criteria and guideline development as well as resolving conflicts with other regulatory agencies. Inherent in the principal program objectives is that technology be provided in the form of usable end products for all functional elements within the Civil Works area of the CE. Costs associated with the technologies will be presented. It is also imperative that the results be presented in a manner such that continued credibility is maintained with other regulatory agencies and environmental-awareness groups. Therefore, an emphasis will be placed on presenting research results in the technical and scientific literature while ensuring results are immediately available to the field through normal CE channels.

WORK AREA A: EFFECTS OF AQUATIC DISPOSAL

Three work units that address long-term effects in the aquatic environment have been initiated at present. The following discussions present the work unit, the progress to date, and the benefits hopefully derived.

Work Unit I: Toxic Substances Bioaccumulation and Biomagnification in Aquatic Organisms

The objective of this work unit is to develop predictive methods for determining the rate and degree of bioaccumulation and biomagnification of toxic substances from contaminated dredged material by aquatic organisms. This will be approached by determining rates and maximum levels of bioaccumulation and biomagnification of PCB's and other toxic substances from a variety of types of dredged material. Biological techniques for use by CE field elements in predicting rates and levels of uptake will be evaluated and refined. Chemical procedures for rapid prediction of rate and magnitude of bioaccumulation from sediment will be developed and assessed. In addition, the magnitude of biomagnification will be determined in short food webs including benthic and epibenthic aquatic organisms. Finally, the potential impact on ecological and human health will be evaluated.

The initial laboratory studies on rates and maximum levels of bioaccumulation reached when aquatic organisms are exposed to contaminated sediment were conducted in FY 82. Species studied were freshwater clam *Corbicula fluminea* and the freshwater crustacean *Macrobrachuim rosenbergii*. Concurrent with these studies were investigations of rapid methods of predicting final

equilibrium bioaccumulation levels and of the feasibility of predicting ultimate levels on the basis of short tests and geochemical analysis of the sediments. A comprehensive literature review on food web biomagnification in aquatic organisms was begun and initial laboratory biomagnification studies were conducted. These studies included a short food chain consisting of the marine worm *Neanthes arenaceodentata* and the fish *Leiostomus xanthurus*.

Future investigations will be expanded to include a wider range of freshwater and saltwater species and dredged material. Species to be studied include the freshwater minnow *Pimephales promelas*, the freshwater crustacean *Daphnia magna*, the estuarine clam *Rangia cuneata*, the marine worm, *Neanthes arenaceodentata* and the estuarine crustacean *Palaemonetes pugio*. Investigations of the ability to predict bioaccumulation from sediment characteristics will be continued and the literature review on food web biomagnification will be completed.

In addition, contaminants which are most often accumulated will be identified and the level of accumulation of these contaminants will be correlated with sediment characterization and interspecific differences. Finally, the actual extent of biomagnification in aquatic food webs will be quantified and related to the health of the contaminated organisms.

Work Unit II: Environmental Interpretation of Consequences from Bioaccumulation

The objective of this work unit is to develop and evaluate procedures for predictive interpretation of potential environmental effects of bioaccumulation of toxic substances from dredged material by aquatic organisms. This work unit ties very closely with Work Unit I in that it is essentially an interpretation of those findings.

The biological consequences of bioaccumulation will be studied in aquatic animals exposed to a variety of types of dredged material containing important organic and metallic contaminants. Correlations of bioaccumulation with biological parameters such as reproduction, growth, and developmental abnormalities will be determined in a variety of representative aquatic organisms. The biological parameters selected for study will be promising first-generation techniques which have not been developed to the point where they are routinely used. These parameters will be assessed in freshwater animals exclusively. The magnitude of change in key parameters which causes deleterious effects to the organisms will be investigated and correlated to the degree of tissue contamination. Through this approach, results of mandated bioaccumulation studies can be realistically interpreted in terms of potential for biological harm.

A comprehensive literature review has begun on the correlation of body burden with biological effects and the consequences of those effects. Preliminary findings of the review indicate that future efforts should concentrate on the effects of halogenated hydrocarbons on the most sensitive infaunal and epibenthic species. Those portions of the life cycle which appear particularly vulnerable should be examined.

In the future, laboratory studies will be initiated to aid in the interpretation of consequences of bioaccumulation based in part on the findings of the literature review as well as newly generated "state-of-the-art" information. These studies will include chronic and acute effects of contaminated sediments on the reproductive potential of benthic organisms. These organisms include the freshwater flea *Daphnia magna*, the marine worm *Neanthes arenaceodentata*, and the estuarine grass shrimp *Palaemonetes pugio*. In addition, methodologies will be developed and tested to determine the ecological survival potential of most sensitive species. These investigations will be conducted so that the degree of tissue contamination may be related to the general overall health of aquatic organisms. This relation will be made in light of the regulatory needs of the permitting process and of disposal activities. In addition, the effects of bioaccumulation on the most sensitive species and life stages will be continued and expanded to include additional organisms and testing protocols. This information will be examined and related to short-term bioassay/bioaccumulation studies currently in use by field personnel.

Work Unit III: Efficiency of Capping in Reducing the Cumulative Effects of Dredged Material Discharge

The objective of this work unit is to evaluate the adequacy of predictive techniques for evaluating cumulative effects through onsite field investigations. This will be approached through field studies which will determine the overall effects of disposal and aid in refining capability for predicting environmental impacts. The environmental efficiency of capping contaminated material with clean material will be determined. Routine dredging operations will be modified so that similar portions of the dredged material are discharged at two separate points. One will be capped and the other uncapped. Effects of the two discharges will be compared.

Six operations suitable for studying the effects of repetitious discharges and capping have been surveyed. In addition, numerous previous capping operations have been reviewed and critically analyzed to provide a sound scientific basis for this study.

In the future, one of the cooperative studies discussed earlier will be selected and initiated with modifications as appropriate based on findings. Disposal operation in which part of the material is capped and part is uncapped will be conducted. Levels of specific contaminants in organisms inhabiting both the capped and uncapped areas will be determined. This will provide the basis for assessing the efficiency of capping. Furthermore, the movement of contaminants and bioaccumulation in key species at the capped and uncapped sites will continue to be studied to determine long-term cap stability and effectiveness over time.

Benefits

Recent legislation requires the CE to assess long-term effects of dredged material disposal on Federal and non-Federal dredging projects. However, long-term effects of dredged material disposal are not well understood and

this lack of understanding has resulted in costly delays on Federal and non-Federal projects and often in the imposition of questionable environmental constraints. The national emphasis on development of coal-exporting facilities will increase the number of major dredging projects. Lack of information on long-term effects can significantly delay these projects since they are subject to international agreements as well as national environmental legislation. Efforts within this work area will provide guidance to the field for assessing potential impacts and on methods of minimizing any adverse impacts of the disposal of dredged material. Results of these studies are necessary to permanently resolve current conflicts on specific major dredging projects where only interim resolutions have been reached with other regulatory agencies. In a recent meeting of a technical committee of the London Dumping Convention, the concept of capping as a mitigating measure for disposal of contaminated dredged material in the ocean was accepted contingent upon the results of further research on the effectiveness of the method. In summary, these studies are required in order for the CE to meet Congressionally mandated requirements on assessing long-term impacts of dredged material disposal.

WORK AREA B: EFFECTS OF UPLAND DISPOSAL

Two work units that address long-term effects in the upland environment have been initiated at present.

Work Unit IV: Techniques for Predicting Effluent Quality of Diked Containment Areas

The objective of this work unit is to develop procedures for estimating the level of contaminants in dredged material containment area effluents. The research approach will involve both field and laboratory investigations. Confined disposal operations will be monitored for conceptual development of laboratory tests for predicting effluent quality of containment areas. A computational procedure will then be developed for determining before-the-fact requirements of the mixing zone. Verification of the developed procedures will be accomplished at several field sites under varying flow and operational conditions.

A first-generation modified elutriate test has been developed in the laboratory using sediments from four disposal operations. In addition, preliminary field verification in support of the laboratory work has been accomplished.

Future research will involve field verification of the modified elutriate test procedure to accurately simulate retention time, settling regime, and other conditions within a disposal area. Additionally, development of an interim technique for prediction of contaminant levels in disposal area effluents will be conducted. The technique will use the modified elutriate test as a basis and will account for transport of particulates and associated contaminants in the disposal area supernatant waters. Finally, sites for later field verification of the predictive technique will be selected and predictive tests for field verification will be carried out.

Work Unit V: Toxic Substances Bioaccumulation in Plants

The objective of this work unit is to develop methods to determine bioaccumulation of toxic substances in plants on dredged material disposal sites.

The approach will initially involve determining the movement of toxic substances from dredged material into both freshwater and saltwater plants and the level of bioaccumulation in the tissues. A variety of types of dredged material will be studied under both flooded and upland disposal environments. A standardized plant bioassay predictive methodology will then be developed. Results of the plant bioassay tests will be interrelated to existing data bases on toxic substances by plants through contracts with (1) the Institute of Soil Fertility, Haren, The Netherlands, for agronomic plants grown on contaminated Dutch sediments; (2) the University College of Wales, Aberystwyth, Wales, UK, for agronomic plants and saltmarsh plants grown on metal mining waste; (3) USDA Beltsville, MD, for agronomic plants grown on sewage sludge amended soils; and (4) the Delta Institute of Hydrobiological Research, Yerseke, The Netherlands, for saltmarsh plants grown on contaminated sediments. These contracts will substantially enhance the interpretation of plant bioassay test results.

The purpose of these contracts will be to compare the WES data on plant uptake of toxic substances by Cyperus esculentus to existing data from other researchers on other plant species in order to take advantage of previous research results and to enhance the interpretation of the meaning of plant uptake data on dredged material.

In 1982, under Freshwater Bioassay Development, comparison of results of laboratory tests to field tests were conducted, but were limited to specific disposal sites. Plant uptake of toxic substances by Cyperus esculentus was compared to other plant species in The Netherlands, Wales, and the United States.

In addition, development of laboratory procedures for a saltwater plant bioassay was initiated in 1982. Spartina alterniflora's growth and uptake of toxic metals from mining waste contaminated sediments were compared in laboratory and field tests in Wales, UK.

Continued comparison of results from laboratory and field plant bioassay testing is planned for the future. Comparison of plant uptake of toxic substances by Cyperus esculentus to agronomic crops grown on sludge-amended soils and complete plant bioassay testing of toxic metal mining waste in Wales, UK, will continue. Also, development of field test procedures will be updated as needed.

In addition, development of the laboratory saltwater plant bioassay procedures will continue. The completion of the comparison of laboratory and field plant bioassay tests in Wales, UK, will be supported by Dutch studies comparing contaminant uptake by Spartina alterniflora to other saltmarsh plants grown on contaminated sediments.

It is planned that the freshwater plant bioassay will be available in 1985 and the saltwater plant bioassay by 1986.

Benefits

Effluent discharges from containment areas into waters of the United States are legally defined as dredged material and consequently are subject to the Corps' Section 404 regulatory authority. These discharges are also subject to more stringent State regulations. The containment areas are subject to the National Environmental Policy Act and, in some instances, may be subject to the Resource Conservation and Recovery Act. These acts require evaluations of impacts at or beyond the present state of knowledge. The results of studies in this work area will allow the CE to make the Congressionally mandated evaluations. The plant bioassays will allow for more sound decisions to be made regarding disposal alternatives (e.g., aquatic, wetland, and terrestrial).

SPECIALIZED DREDGES DESIGNED FOR BOTTOM SEDIMENT DREDGING

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ABSTRACT

This paper describes the functions, characteristics, and turbidity prevention or controlling effect of specialized dredges designed for bottom sediment dredging and developed for exclusive practical use.

In bottom sediment dredging, the prevention or controlling of turbidity arising from the dredging operation is an important problem.

When compared with cutter suction dredging, the specialized dredges can significantly reduce the potential generation of turbidity.

INTRODUCTION

Since the late 1960's, Japan has made remarkable progress in economy and industry.

As a result of coastal development and factory construction, deterioration of the environmental conditions and hazardous pollution in water, air, noise, or vibration have frequently taken place. For these reasons, strict regulations and laws have been imposed on the sources of pollution. One environmental goal is the removal of sediments containing toxic materials such as mercury and PCB, a large amount of oil, or organic substances, and improvement of the water quality.

Removal of the contaminated sediment would improve the quality of the water. Therefore, removal must be carried out without secondary pollution likely to accompany removing work. In the past, this has been difficult to perform. To solve this problem, we have developed a "REFRESHER," anti-pollution dredging system, based on the conventional cutter suction dredge, and are performing sediment removing works using this system.

When compared with the conventional suction dredging, the REFRESHER anti-pollution dredging system has accomplished the specified purpose of preventing secondary pollution.

FUNCTIONS NECESSARY FOR BOTTOM SEDIMENT DREDGES

Almost all dredging works to date have been conducted for land reclamation and deepening and maintaining navigation channels and anchorages for increasing traffic and safety.

However, bottom sediment dredging is intended to improve water quality and therefore must be undertaken without causing secondary pollution. Bottom sediments are thin layers with high water contents containing silt, clay, debris, and other organic substances as well as toxic materials.

Therefore, for specialized dredges to dredge bottom sediments with safety, within a short period of time, and in an economical way they must provide the following functions:

a. The dredge must fully and completely remove bottom sediments and prevent generation of turbidity. Although we want to prevent the generation and dispersion of turbidity arising from dredging, we must examine the factors contributing to the generation of turbidity in the conventional cutter suction dredges:

   (1) Turbidity arising from the cutter suction dredging operation. As the cutter used for dredging sandy materials and conveying in the suction mouth is rotating, the materials not taken into the suction mouth are scattered. Figure 1 shows the cutter used for the model test and the turbidity arising with cutter operating at a low speed. This turbidity occurred frequently at the rear side of the cutter and stayed along the cuts or windrows.

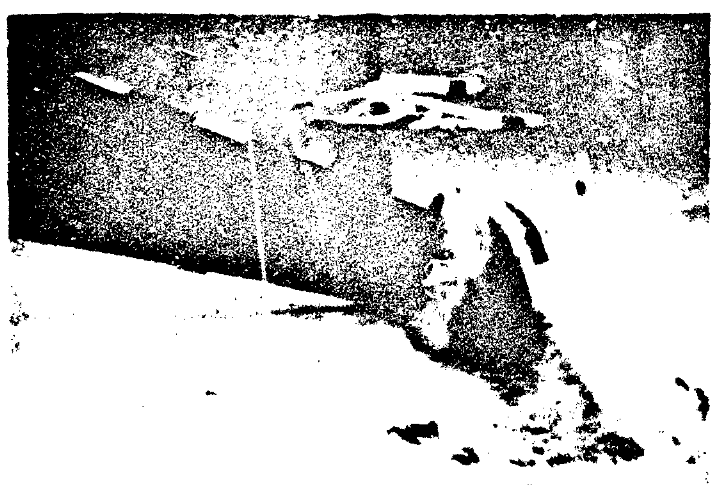


Figure 1. Dredging experiment by cutter model

(2) Turbidity arising from installation and reinstallation of anchors and spuds. Dispersion and agitation of dredged sandy materials take place when the anchors and spuds are installed/reinstalled.

(3) Turbidity arising from the maneuver of dredges. Silty/clayey materials attached to the wires of dredges are scattered when the swing wires are used for swinging right and left and the anchoring wires for smooth shifting are set.

(4) Turbidity caused by the lower part of the ladder head when dredging is conducted in shallow waters and/or in thick layers. While gaining access to the bed point, the ladder head causes water currents that scatter the dredged material, thereby causing turbidity.

Of these four factors, factors (2) and (3) are disregarded due to negligible turbidity generation. However, factors (1) and (4) are considered influential. Therefore, measures to prevent turbidity generation shall be focused on the turbidity arising from the cutter suction dredging operation and turbidity caused by the ladder head.

Complete removal of bottom sediments is necessary. Sandy materials excavated by the cutter are conveyed into the suction mouth. As the ladder angle (the dredging depth) increases, the suction mouth position becomes higher from the sea bottom and all of the sandy materials are not conveyed to the suction mouth and part of the material is scattered behind the cutter. When dredging in thin layers, such as in bottom sediments, additional excavation is necessary to obtain the required depth and, therefore, an additional volume of dredging is inevitable. For the dredging of the bottom sediments, the minimum volume of additional dredging is required to conduct the complete removal of the designed dredging materials to increase efficiency in transport and disposal of the bottom sediments.

b. The dredge must excavate the bottom sediments in high concentration. When dredging thin layers of the bottom sediments by cutter suction dredges, the suction mechanism takes in surplus water and has a low mud concentration. When placing bottom sediments at the disposal areas, less spill water is preferable because of the difficulty in securing disposal areas. Therefore, high concentration dredging is preferable.

c. Competent operation of the dredges is necessary. Operators of dredges must prevent generation and dispersion of the bottom sediments and must dredge in high concentration. Though dredges can provide the above-described functions, they do not necessarily do so because of geotechnical, topographical, or operating conditions. Therefore, operators must confirm, while dredging, that the generation and dispersion of turbidity are prevented and that the bottom sediments are completely removed. In addition, operators must understand the proper thickness of the bottom sediments to be dredged, and must maintain a high concentration, proper swing speed, and other optimal operating conditions.

CHARACTERISTICS OF THE REFRESHER ANTI-POLLUTION DREDGING SYSTEM

Functions

Figure 2 and the following paragraphs show a concept of the REFRESHER which provides the functions necessary for dredging the bottom sediments.

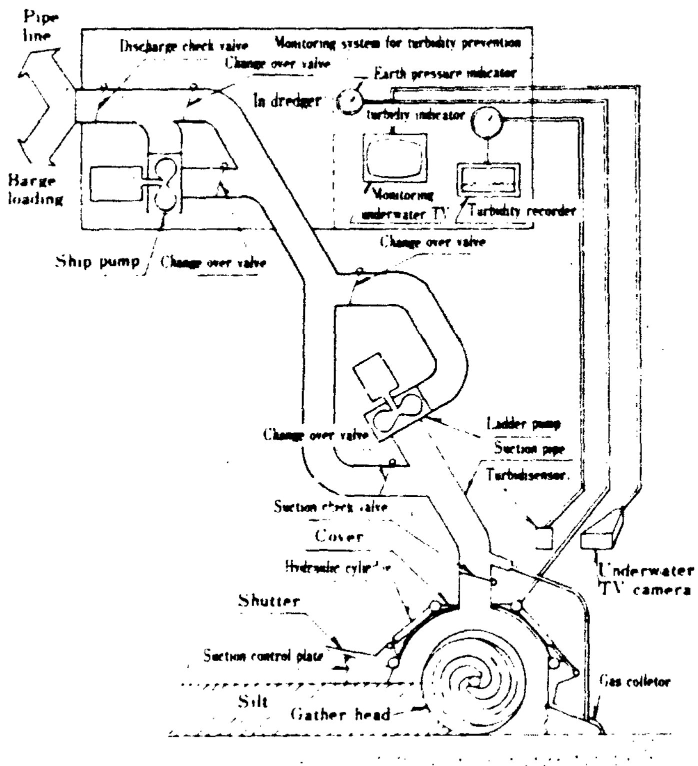


Figure 2. Concept ot REFRESHER system

a. Prevention of turbidity and complete removal of the bottom sediments.

Prevention of turbidity

(1) Gather head (see Figure 3)
The gather head is a ribbon blade with a reducing spiral at the front end. It causes less scattering by centrifugal force of sand, and collects the sand in the suction side while cutting a variety of earth, from soft mud to hard ground. Revolution of gather head is convertible to cope with the property of the earth to be dredged, the dredging thickness, and the swing speed.

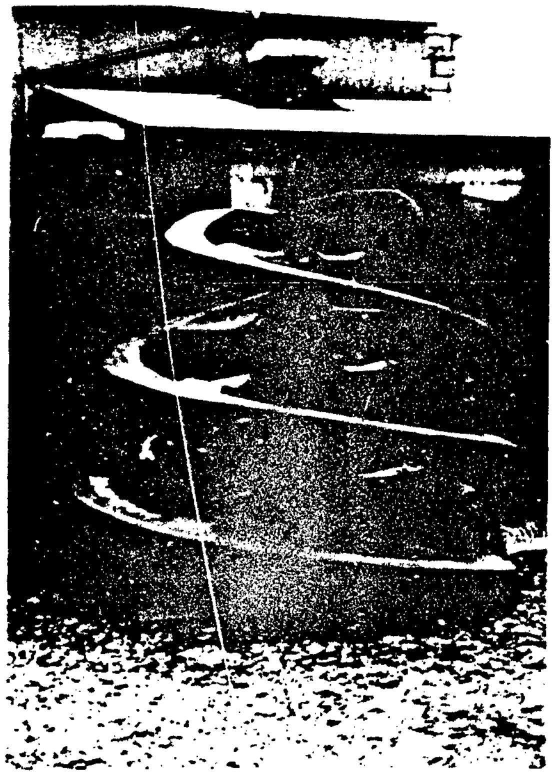


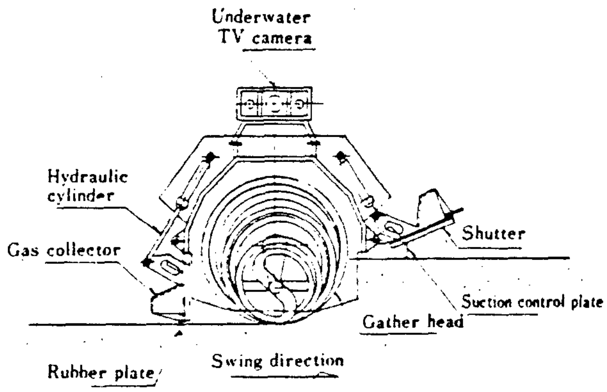
Figure 3. Gather head

(2) Cover and shutter
Figure 4 shows a front and side view of the special mud collector. As shown in the figure, the cover which completely conceals the gather head has a shutter adjustable to open or shut by an adjuster plate for suction water and is structured such that it does not leak any turbidity generated by dredging.

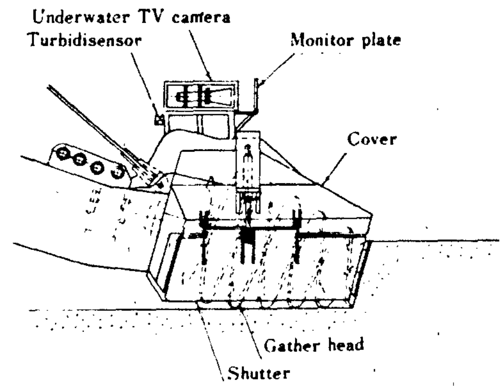
(3) Check valve, gas collector, and other equipment
Check valves at the suction and discharge side of the pump prevent the back flow of the sediment water into discharge pipes in an emergency. The gas collector apparatus (shown in Figures 2 and 4) collects the gas produced while dredging and delivers the gas to the suction pipe.

<u>Complete removal of the bottom sediments</u>

(1) Position controller (Figure 5)
The position controller controls the revolution loci of the gather head to the angle parallel to the ground and to control this angle to meet the dredging depth and will attain the complete dredging without any sediment residue. Moreover, in this case, the maximum prevention of sediment dispersion will be attained and condition of dredged loci will have no wave types with a less excavation surplus after dredging.

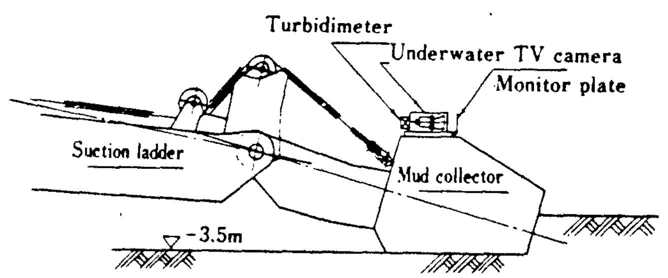


(a) Front view

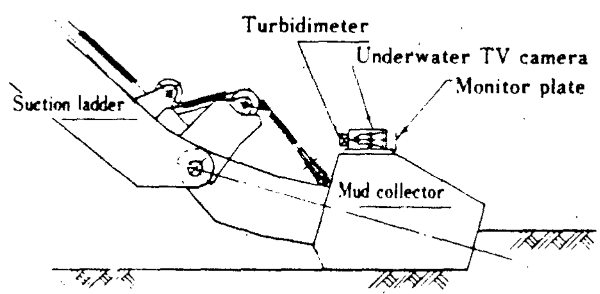


(b) Side view

Figure 4. Special mud collector



(a) Shallow dredging (-3.5m)



(b) Deep dredging (-20.0m)

Figure 5. Angle adjustment by position controller

b. High concentration dredging

(1) Ladder pump and ship pump
A centrifugal pump is provided at the ladder to conduct suction of the sediments in high concentration. In addition, a ship pump is used in combination for discharging dredged sediments for a long distance. A series operation of ladder pump and ship pump will be able to discharge the dredged material about 3000 m.

(2) Cover, shutter, and other equipment
Cover, shutter, suction control plate, position controller, etc., help prevent excess water in high concentration dredging.

c. Operation monitoring

Monitoring turbidity

(1) Monitoring by underwater TV camera
An underwater TV camera is installed at the top of the cover; operators can observe the turbidity conditions above the head at any time from the monitor in the operation room. The system consists of an underwater camera, a monitor TV video system, and a recording of the date on the picture. Figure 6 shows a monitor and video system in the operation room.

(2) Monitoring by turbidimeter
The picture on the monitor cannot indicate the extent of turbidity quantitatively. Therefore, a sensor or turbidimeter is set at the same point as the TV camera and operators can observe the turbidity conditions by monitoring the TV and its extent by the turbidimeter.

Understanding operating conditions

(1) Dredging depth meter
To understand the correct water depth before and after dredging, sets of a transmitter and a receiver of the echo sounder are installed at both sides of the cover. As the measured result is indicated and recorded in the operating room, the operator can promptly find the dredging depth, dredging earth thickness, and operation conditions, and can ensure that the dredging is fully completed to the required thickness (see Figure 6).

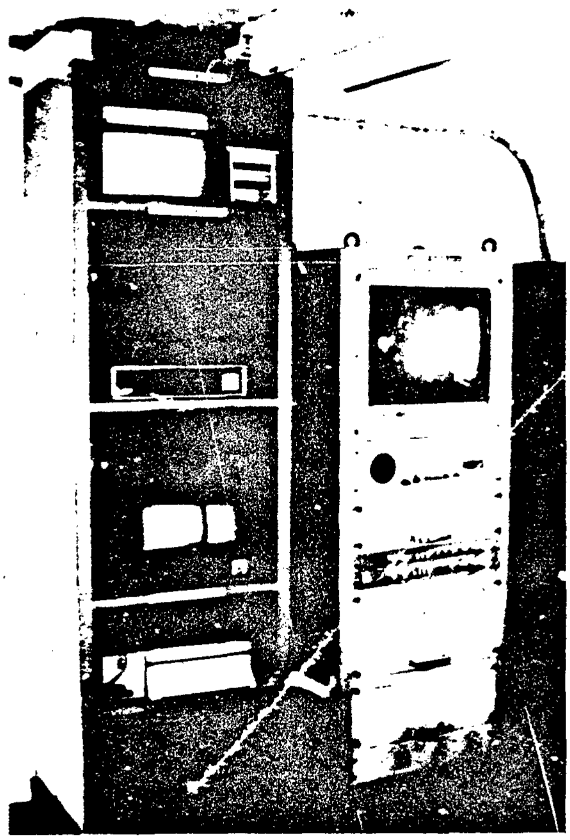
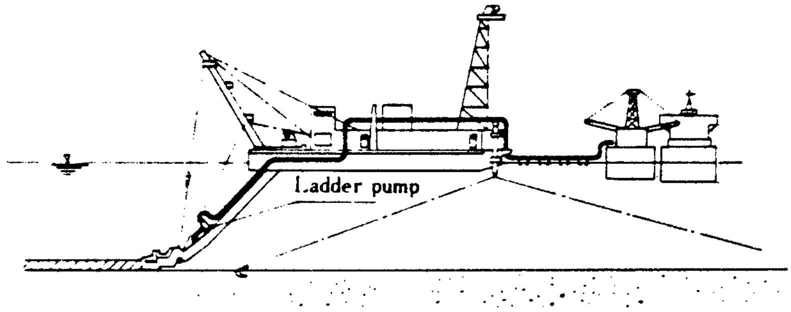


Figure 6. Monitor TV and echo sounding recorder

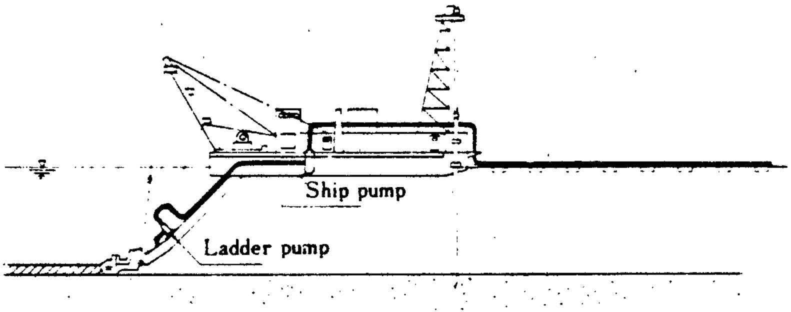
Transportation Methods

In the REFRESHER system, two transportation methods are available: barge loading and pipeline (see Figure 7).

At present, the REFRESHER system dredges are: REFRESHER No. 6 Fuyo; REFRESHER No. 3, and MINI-REFRESHER Tokyo Maru. The former two dredges are suitable for dredging large- to medium-scale work such as a large amount of sediments promptly deposited over the wide range; the MINI-REFRESHER Tokyo Maru is a portable dredge suitable for small-scale work in narrow areas.



(a) Barge loading method



(b) Pipeline method

Figure 7. Transportation methods

Specifications

Various characteristics of the REFRESHER system have been described. Given below are the main specifications; Figure 8 gives the general arrangement of REFRESHER No. 3 for easier reference.

General items

Dredging depth:	3.5 to 20.0 m
Discharge distance:	Barge loading, 3000 m
Dredging capacity:	150-400 m^3/hr
Hull dimensions:	L.45.60 m × B.13.50 m × D.3.30 m
Displacement at full load:	1200 tons
Draft at full load:	2.20 m

Special mud collector

Mud collector drive unit:	DC 100 kw, 3-15 rpm
Shutter:	Hydraulically remote control
Position controller:	"
Gas collector:	Ejecter system

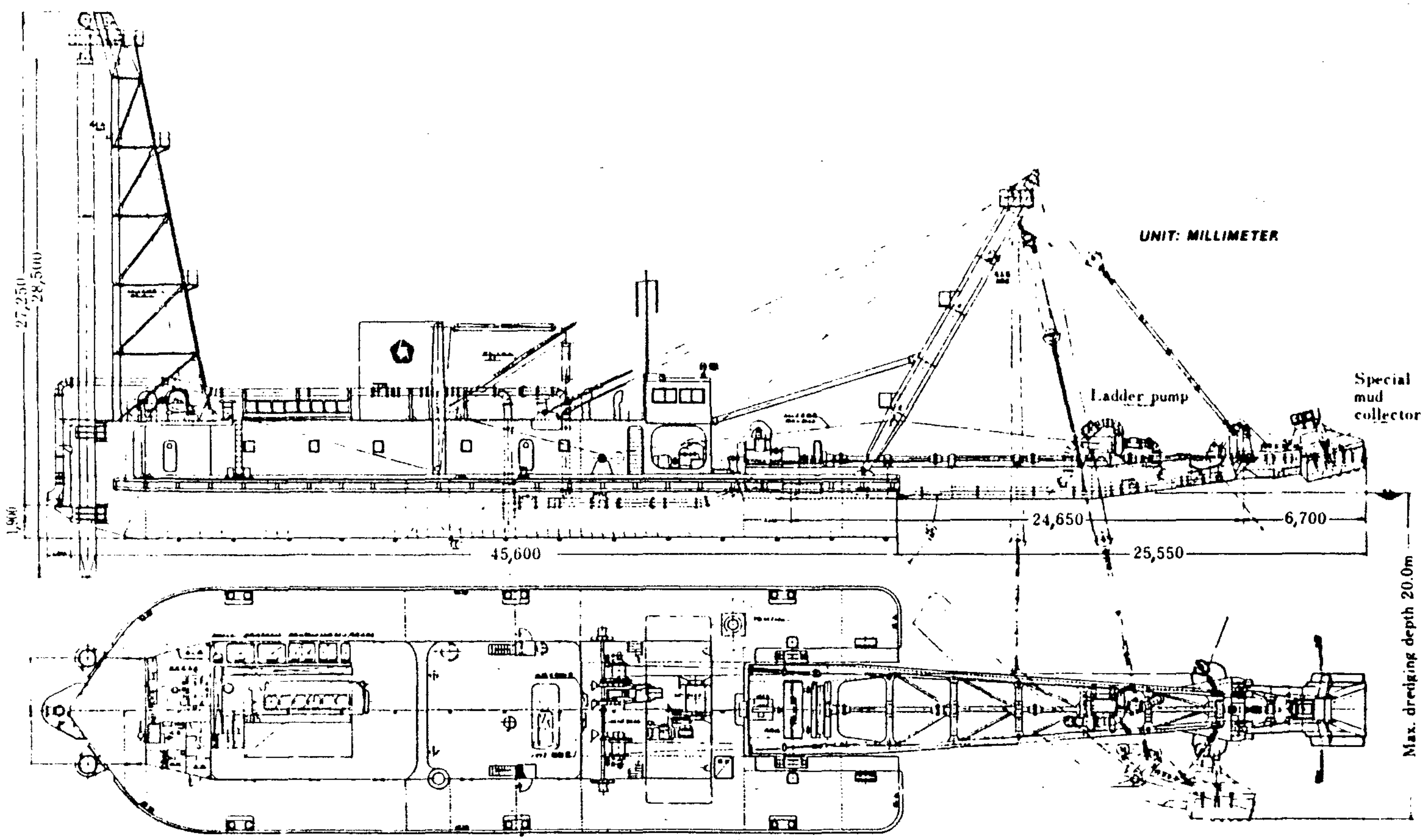


Figure 8. General arrangement of REFRESHER No. 3

Dredging pump

	Ladder pump	Ship pump
Type	Centrifugal	Centrifugal
Nominal shaft Horsepower	150 PS	1800 PS
Capacity	800 to 2000 m^3/hr	800 to 2000 m^3/hr
Total head	10 to 20 m	20 to 50 m
Rpm	490 to 700	200 to 310
Prime mover	AC 110 kw (Frequency conversion control)	D 2000 PS (Diesel engine)
Suction pipe dia./Discharge pipe dia.		400A/400A
Suction check valve, change over valve		

Operation monitoring system

Underwater monitoring TV:	Underwater TV camera, monitoring video, light
Turbidity monitoring:	Underwater turbidimeter
Dredging depth meter:	Echo sounder

TURBIDITY PREVENTION BY REFRESHER SYSTEM DREDGES

The REFRESHER anti-pollution dredging system was developed for practical use in preventing turbidity arising from dredging. Illustrated and explained below are the results of our investigation into the turbidity around ladder heads of conventional cutter suction dredges and REFRESHER dredges.

Turbidity by Cutter Suction Dredges

The dredging work in Port Y (see reference 1) involves dredging of an anchorage area (10 m deep, about 135,000 m^2 in dredging area, and about 530,000 m^3 in dredging volume) by means of cutterless suction dredging (without the cutter) of 1.i- to 1.7-m-thick upper layers of soft clays and cutter suction dredging of 1.9- to 3.0-m-thick lower layer (Figures 9 and 10).

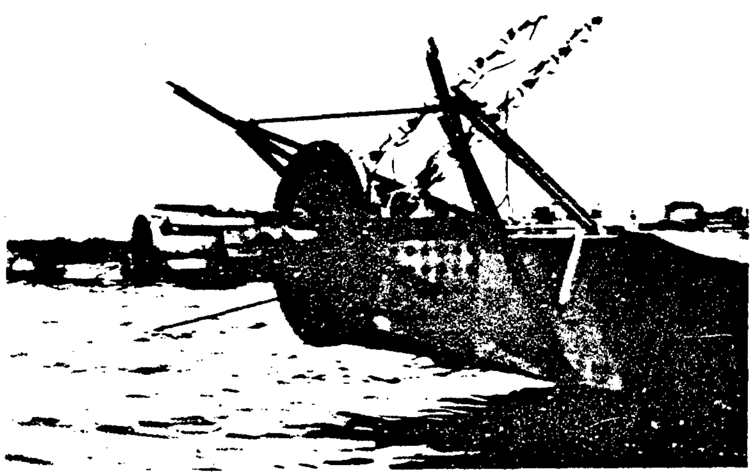


Figure 9. Cutterless suction dredging

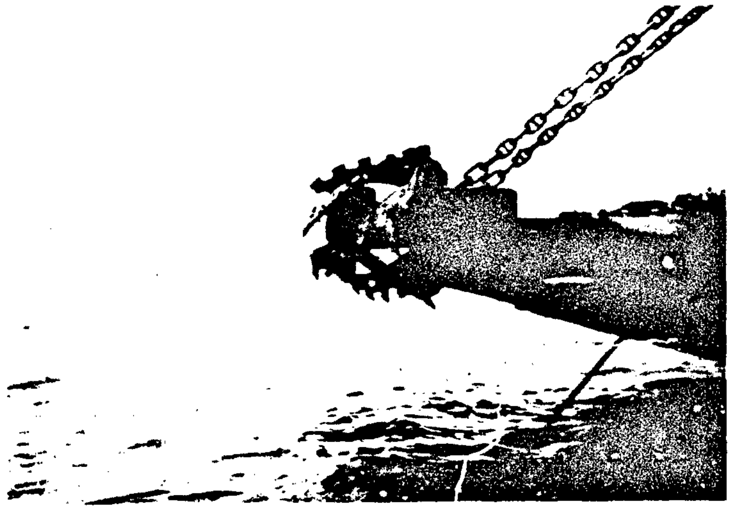


Figure 10. Cutter suction dredging

Stated below are the particulars of the dredge, physical properties of the dredged material, operation conditions, and investigation results of the turbidity.

Major Specifications of the Dredge No. 6 Fuyo

General items

Hull dimensions:	L.53.68 m × B.14.00 m × D.3.81 m
Displacement at full load:	1880 tons
Draft at full load:	2.74 m
Discharge distance:	5000 m
Dredging capacity:	200 to 1300 m^3/hr (Mud concentration of more than 30%)
Dredging depth:	6 to 21 m
Dredging pump: Prime mover:	F.P. Gas Turbine (Nominal) 4000 PS

Physical Properties of Dredged Material

Specific gravity:	2.63 - 2.70
Grain-size distribution	
Upper:	Silty clay (Partly about 15% sand inclusive)
Lower:	Silty clay (Partly about 50% of sandy gravel inclusive)
Wet density	
Upper:	1.25 - 1.40 g/cm^3
Lower:	1.50 - g/cm^3

Operating Conditions

Table 1 indicates the operation conditions of the cutterless suction dredging (for upper layers) and the cutter suction dredging (for lower layers)

Table 1. Operating conditions (1)

	Cutterless suction dredging (upper layer)	Cutter suction dredging (lower layer)
Swing speed (m/min)	5 - 10	5 - 10
Cutter rpm	———	15
Dredging thickness (m)	0.5 - 1.0	0.6 - 1.0
Spud moving nterval (m)	1.5 - 2.0	2.0
Flow rate in pipe (m/sec)	4.3 - 4.8	3.5 - 4.5

Note: Diameter of discharge pipe: 670 mm

Turbidity Investigation Details and Results

To comprehend the scope and extent of turbidity around the ladder head, turbidity and visibility were measured in seawater pumped up by a simple automatic sampler and obtained from the positions shown in Figure 11.

To comprehend the influence around the dredge, measurement of turbidity and visibility was made in the seawater at the points shown in Figure 12. Since the relation SS (Suspended Solids) = 1.7 × Tb (Turbidity) was obtained, the turbidity is to be expressed hereafter by the conversion basis of SS.

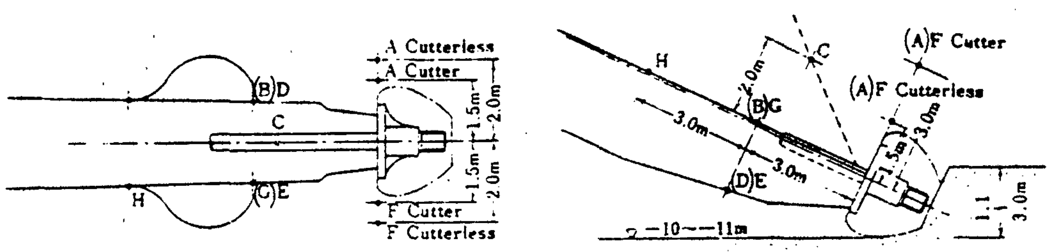


Figure 11. Checking position of ladder head for cutterless suction dredging and cutter suction dredging

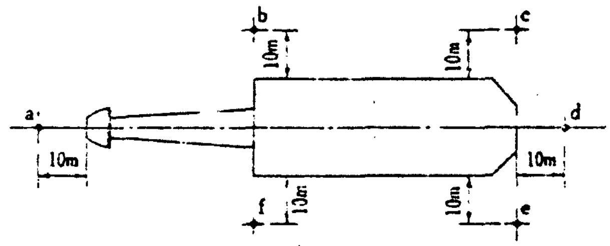


Figure 12. Measurement points around dredge

The highest velocity of the curren... during the surveying period was only about 5 cm/sec, not enough to cause any influence.

The investigation results are summarized below.

Swing speed, rpm of the cutter, dredging thickness, etc., of every item of the operation conditions greatly affect turbidity generation during cutterless suction dredging. Figure 13 shows the relation between the dredging thickness and SS at the time of the cutterless suction dredging. Note that the larger the dredging thickness, the more the SS increases.

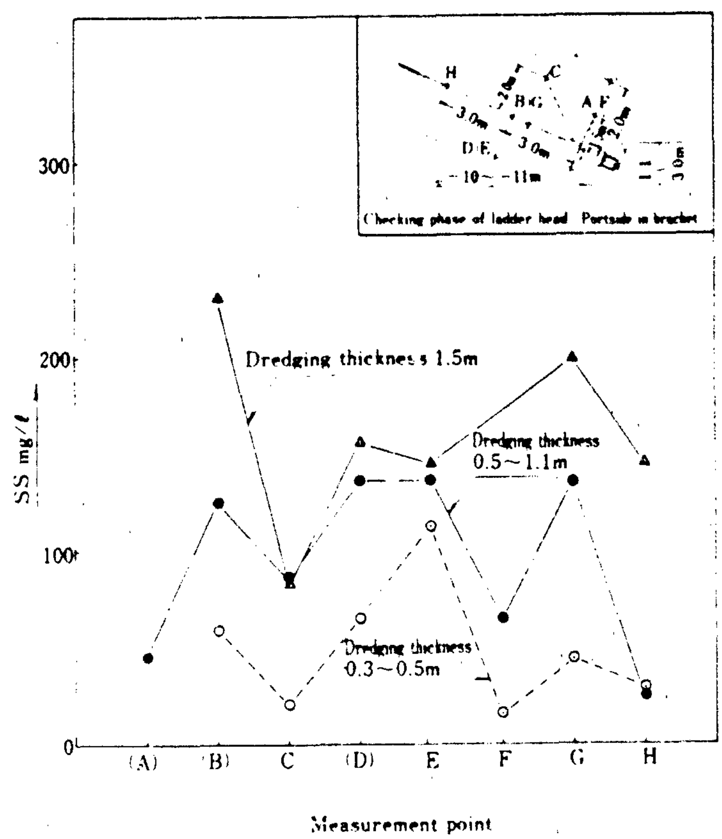


Figure 13. Relation between dredging thickness and SS (cutterless suction dredging)

Swing speed, swing direction, etc., were not found to influence turbidity during cutter suction dredging. Figure 14 shows the average SS values at respective measuring points during cutterless suction dredging and cutter suction dredging. Turbidity during cutterless suction dredging was almost half that of cutter suction dredging.

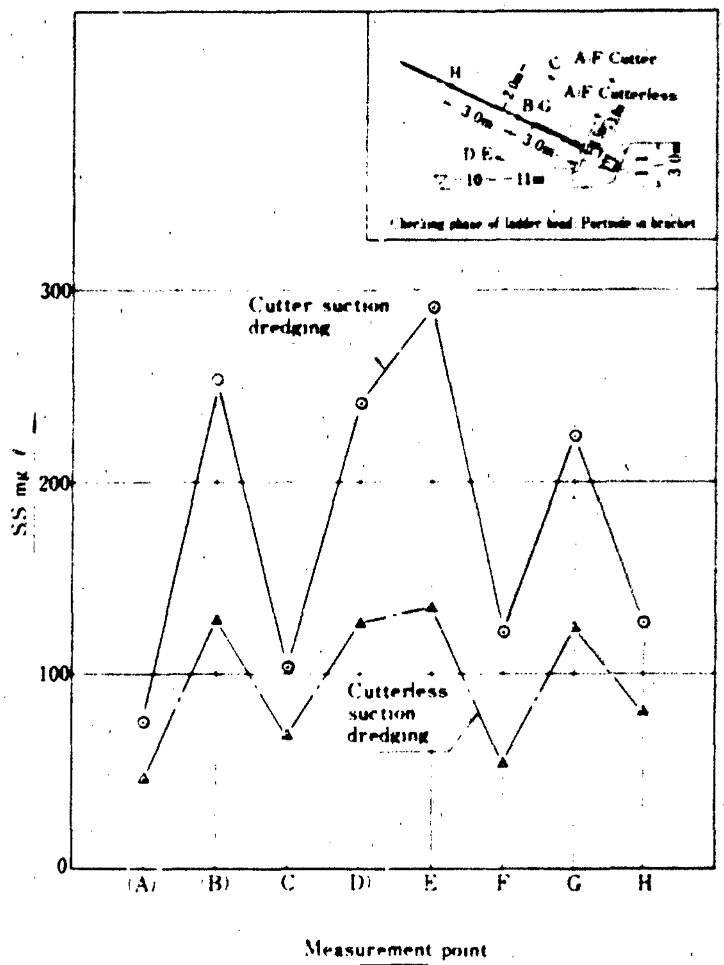


Figure 14. Comparison in SS of ladder heads between cutter suction dredging and cutterless suction dredging

Figure 15 shows turbidity in areas and in degrees during cutter suction dredging. According to Figure 15, when turbidity from cutter suction dredging falls to 5 m × 10 m, turbidity in degrees averages 100 to 200 mg/l SS. If continuous generation of 100 to 200 mg/l turbid water is assumed within this area, the turbidity is generated at a rate of 500 m^3/min (= 5 m × 10 m × 10 m/min) for a swing speed of 10 m/min.

Portside in bracket . Unit: SS : mg/ℓ

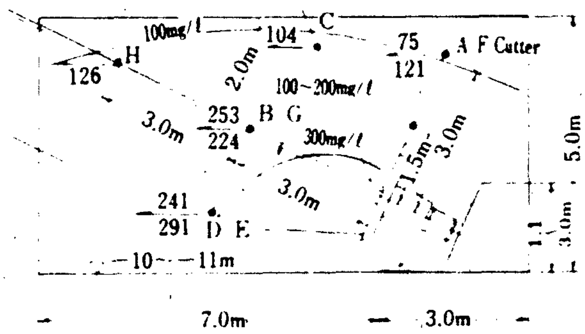


Figure 15. Turbidity in areas and in degrees by cutter suction dredging. Portside in bracket Unit: SS, mg/ℓ

Table 2 indicates the net contents of the turbidity generation, taking into consideration the operation conditions and the dredging volume during cutter suction dredging. About 5 tons of turbidity per hour is generated. Most of the generating turbidity, however, settles to the sea bottom.

Table 2. Net contents of turbidity generation (cutter dredging) (1)

Swing speed (m/min)	Turbidity area (m^2)	Average SS (mg/1)	Min/Hr turbidity generation (t/min)	(t/hr)	Dredging volume (m^3/hr)	Net contents of turbidity generation (t/m^3)
10		200				
	50		0.10	5.19	600	$8 \cdot 10^{-3}$
(5 - 10)		(100-200)				

Figure 16 is the result of measurement of the turbidity around the dredge. The figure shows that, although the turbidity is observed at points 7 m (sea bottom - -10 m) below water level, the turbidity is much smaller than around the ladder head. Another investigation conducted at a remote point revealed that the influence over turbidity is nearly nonexistent over 100 m beyond the dredge.

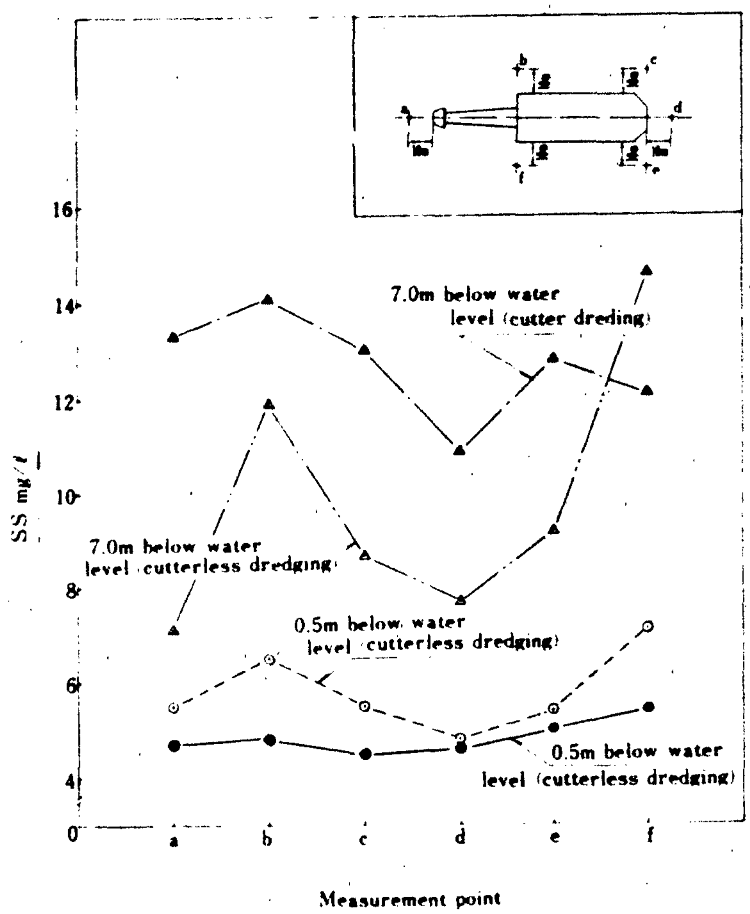


Figure 16. Turbidity around dredge

Turbidity by REFRESHER dredge (T Bay)

Bottom sediment dredging work in T Bay involved about 300,000 m^2 in dredging area and about 150,000 m^3 in dredging volume. The REFRESHER system has dredged the bottom sediments in about half the designated area, transported by means of pipelines to the disposal area.

Major Specifications of the Dredge REFRESHER No. 6 Fuyo

General items

Hull dimensions:	L.53.68 m × B.14.00 m × D.3.81 m
Displacement of full load:	1880 tons
Draft at full load:	2.74 m

Discharge distance:	Barge loading = 5000 m
Dredging capacity:	200 to 1,300 m^3/hr
Dredging depth:	6 to 21 m

Dredging pump

	Ladder pump	Ship pump
Type:	Axial flow	Centrifugal
Nominal shaft: Horsepower:	200 PS	3600 PS
Capacity:	700 to 5000 m^3/hr	700 to 5000 m^3/hr
Total head:	4 to 7 m	10 to 100 m

Operation monitoring system

Same as REFRESHER No. 3

Physical Properties of Dredged Material

Physical properties of the dredged material are indicated in Table 3. The dredged material is sandy silt.

Table 3. Physical properties of dredged material (1)

Specific gravity	Grain-size distribution (%)			Natural water content (%)	Wet density (g/cm^3)
	Sand	Silt	Clay		
2.68 - 2.80	7 - 19	65 - 75	10 - 18	146	1.30 - 1.32

Operating Conditions

Table 4 indicates the operating conditions.

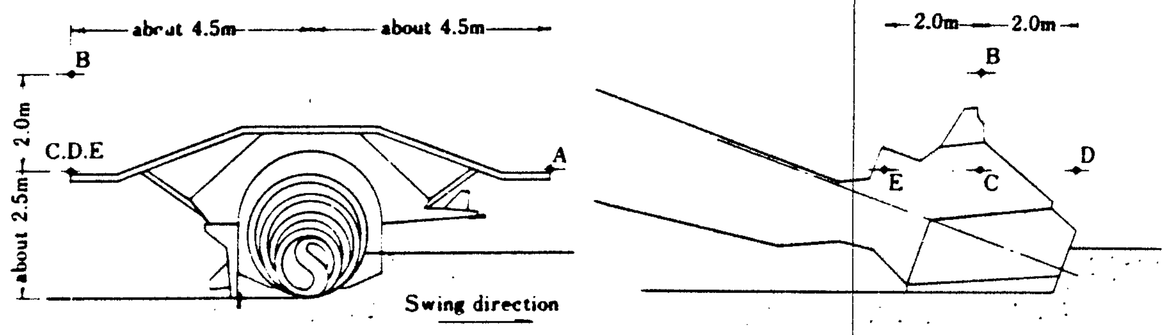
Table 4. Operating conditions (2)

Swing speed (m/min)	Gather head rpm	Dredging thickness (m)	Spud moving interval (m)	Dredging depth (m)	Flow rate in pipe (m/sec)
5 - 10	3	0.4 - 0.8	2.5	7.0 - 9.0	3.0

Note: Diameter of discharge pipe: 610 mm

Turbidity Investigation Details and Results

To comprehend the scope and extent of turbidity around the ladder head, turbidity was measured by installation of the turbidisensor at the phases shown in Figure 17. The turbidity measured at points 0.5, 2.0, and 5.0 m below the water level are shown in Figure 18. The turbidity was measured at points 1 through 9 at three different depths.



(a) Front view (b) Side view

Figure 17. Checking position of ladder head

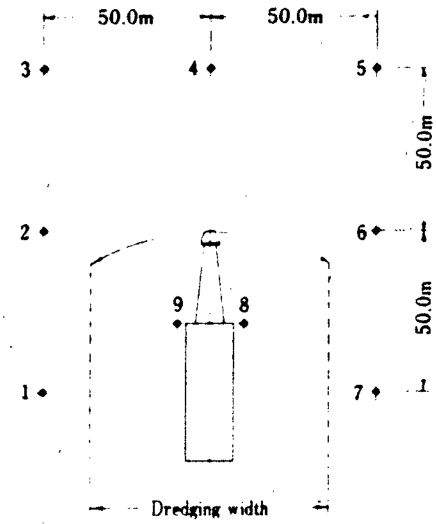


Figure 18. Measurement points around dredge

The relation SS = 1.5 Tb was obtained and the current at the highest speed during the surveying period was about 10 cm/sec. Figure 19 shows the relation between the swing speed and the turbidity at point C of the ladder head. It was found that the more the swing speed increased, the larger the degree of turbidity became and that the degrees of turbidity were less than a few mg/l at a swing speed of 5 m/min and around 20 mg/l at 10 m/min.

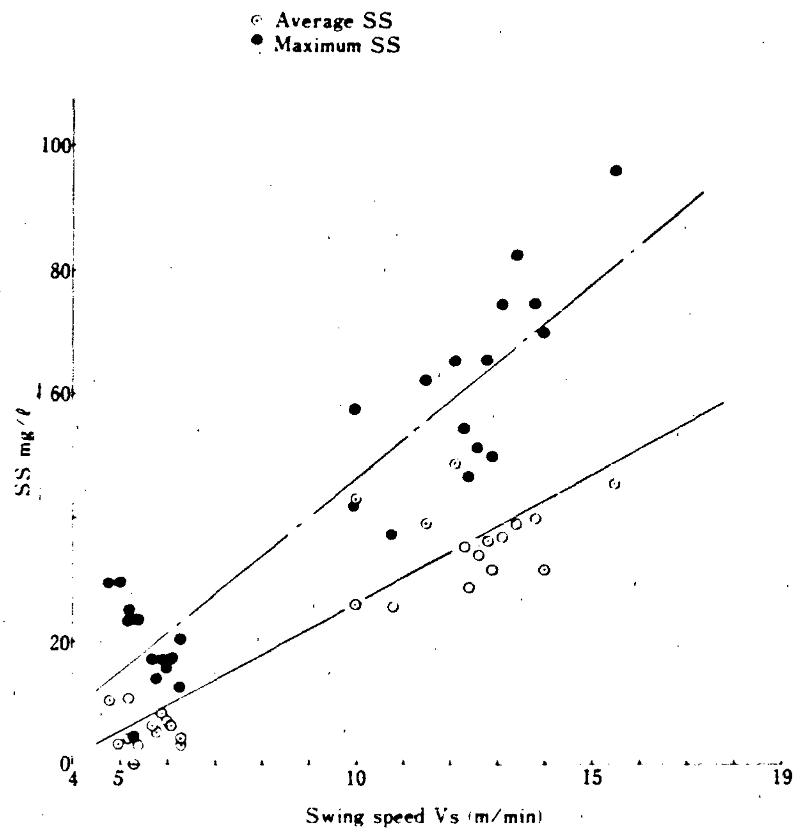


Figure 19. Relation between swing speed and turbidity at point C

Figure 20 shows the relation between swing speed and finish performance (the difference between the actual finished depth and the assumed finish depth). When the swing speed is slow, the actual finished depth becomes deeper than the assumed finish depth (in case of a swing speed of 5 m/min, the actual finished depth is about 0.3 m deeper than the assumed finish depth); as the suction efficiency is good, there is little turbidity generation. However, mud sediment concentration is lower due to suction of excess water.

On the other hand, the more the swing speed increases, the less the actual finished depth (about 0.1 m for 10 m/min); as the suction efficiency worsens, the more turbidity is generated.

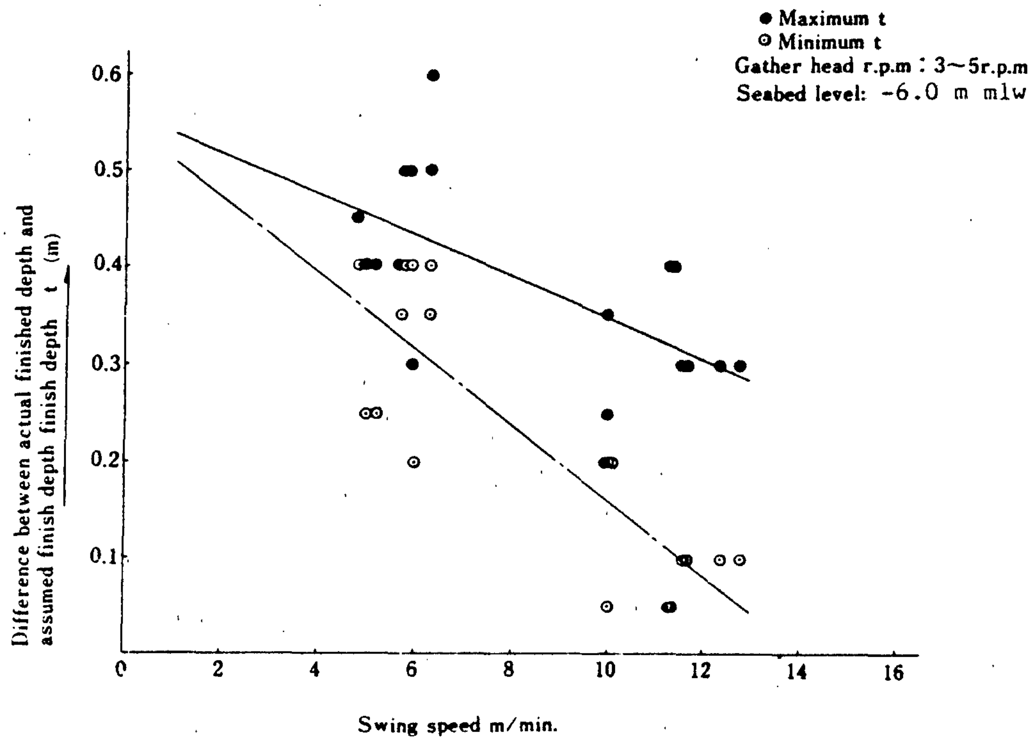


Figure 20. Relation between swing speed and finish performance (difference between actual finished depth and assumed finish depth)

Figure 21 shows the average SS and the turbidity area, obtained from measuring turbidity from points A to E. The SS value is much smaller than that of cutter suction dredging.

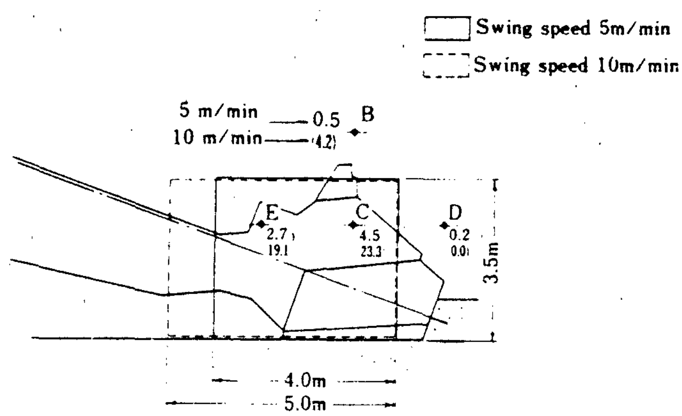


Figure 21. Average SS and turbidity area (1)

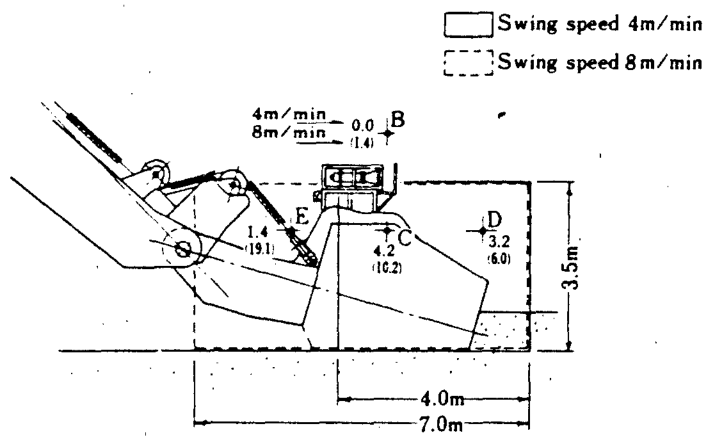


Figure 23. Average SS and turbidity area (2)

Table 8 indicates net contents of turbidity generation, taking into consideration the operation conditions and the dredging volume. The values were 0.01 t/hr at a swing speed of 4 m/min and 0.15 t/hr at 8 m/min, slightly larger than the values found at T Bay.

Table 8. Net contents of turbidity generation

Swing speed (m/min)	Turbidity area (m^2)	Average SS (mg/l)	Min/Hr turbidity generation (t/min)	(t/hr)	Dredging volume (m^3/hr)	Net contents of turbidity generation (t/m^3)
4	14	4.2	2.35×10^{-4}	0 011	144	0.08×10^{-3}
8	24.5	19.1	3.74×10^{-3}	0.150	240	0.63×10^{-3}

Figure 24 shows the measurement results of turbidity around the dredge. The changing values of SS are based on the elapse of time at measurement points 4, 5, and 6 on the downstream side of the currents. Since all SS values were smaller than the value prior to dredging, no influence by dredging operation can be observed.

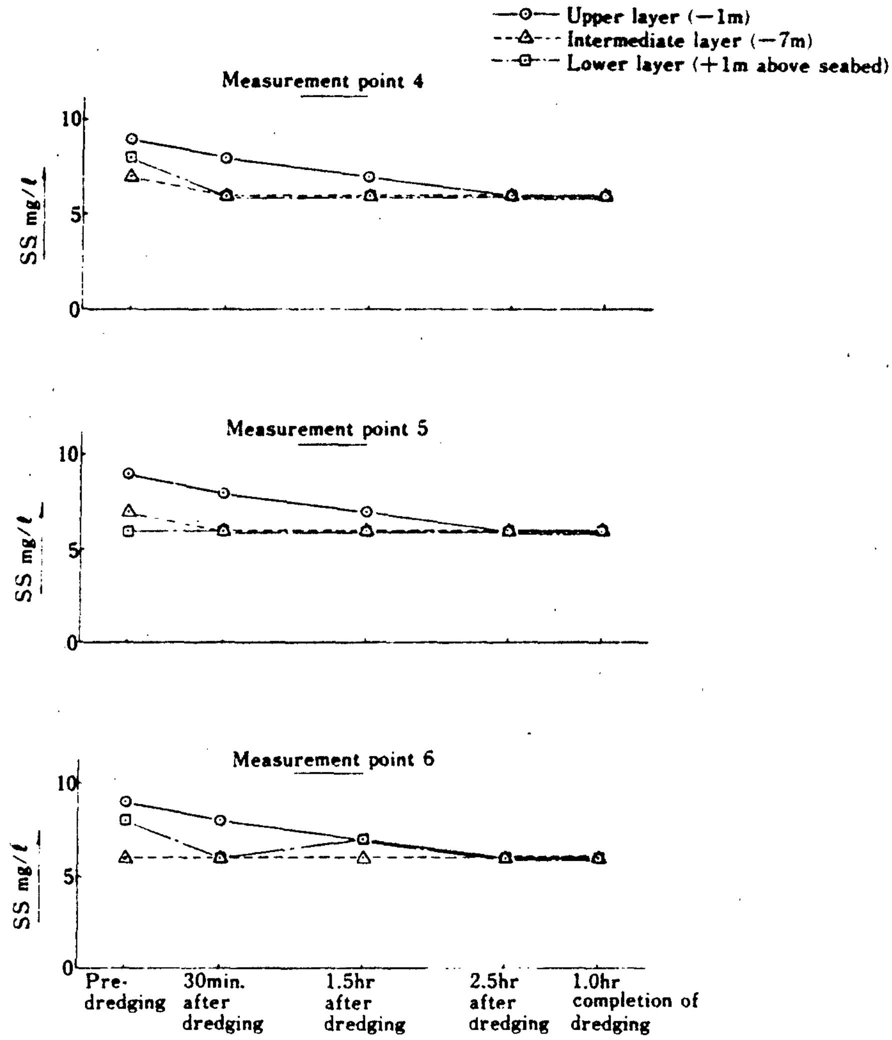


Figure 24. Turbidity around dredge (2)

Table 9 indicates the results of the dredging efficiency; the apparent mud concentration is 28%.

Table 9. Dredging efficiency

Total operating time (hr)	Total dredging time (hr)	Total discharge volume (m^3)	Total dredging volume (m^3)	Dredging volume per operating hour (m^3/hr)	Dredging volume per dredging hour (m^3/hr)	Apparent mud concentration (%)
95.0	59.42	69,118	19,320	203	325	28

WORK EXPERIENCES

Table 10 outlines work experiences of REFRESHER dredges for reference.

Table 10. Work experiences of REFRESHER dredges

Name of work	Time for completion	Dredging Volume (m^3)	Dredging area (m^3)	Particulars of work
Bottom sediment dredging work in T Bay	Dec 1976 to Mar 1977	104,390	143,000	Dredged, pipelined for 1365 m and discharged by spreading outlet installed pontoon
Dredging work in M Bay	F.Y. 1980 to F.Y. 1981	14,790	23,456	Employed REFRESHER No. 3. Dredged and transported by a 2200-m^3 sand barge for a distance of 10 km to dumping area
Dredging work in Port Y	June 1981 to Sep 1981	29,720	161,000	Employed REFRESHER No. 3. Dredged, transported 7.4 km by 1900-m^3 sand barge and unloaded by 1350-PS unloader
Dredging work in Port T	F.Y. 1977 to F.Y. 1982	175,980	158,170	Employed MINI-REFRESHER Tokyo Maru. Dredged, transported 8.5/13 km by 200/400 m^3 sand barges and unloaded by 250-PS unloader

CONCLUSIONS

Table 11 summarizes the comparison of turbidity generation between cutter suction dredging and REFRESHER dredging. Disregarding the slight difference in physical properties of the dredged material, turbidity generation per hour was about 5 tons by cutter suction dredging and about 0.01 to 0.1 ton by REFRESHER dredging. Therefore, turbidity generation arising from REFRESHER dredging is about 1/50 of that from cutter suction dredging under any circumstances.

The REFRESHER dredging system has the capability to prevent the generation of turbidity. However, some allowance should be given to the REFRESHER dredging, when considering dredging efficiency.

Table 11. Comparison of turbidity generation between cutter suction dredging and REFRESHER dredging

Item	Swing speed (m/min)	Turbidity area (m^2)	Average SS (mg/1)	Min/Hr turbdity generation (t/min)	(t/hr)	Dredging volume (m^3/hr)	Net contents of turbidity generation (t/m^3)
Cutter suction	10 (5-10)	50	200 (100-200)	0.10	5.19	600	8×10^{-3}
REFRESHER dredging in T Bay	5	14	4.5	3.15×10^{-4}	0.011	273	0.04×10^{-3}
	10	17.5	23.3	4.08×10^{-3}	0.107	393	0.27×10^{-3}
REFRESHER dredging in M Bay	4	14	4.2	2.35×10^{-4}	0.011	144	0.08×10^{-3}
	8	24.5	19.1	3.74×10^{-3}	0.150	240	0.63×10^{-3}

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